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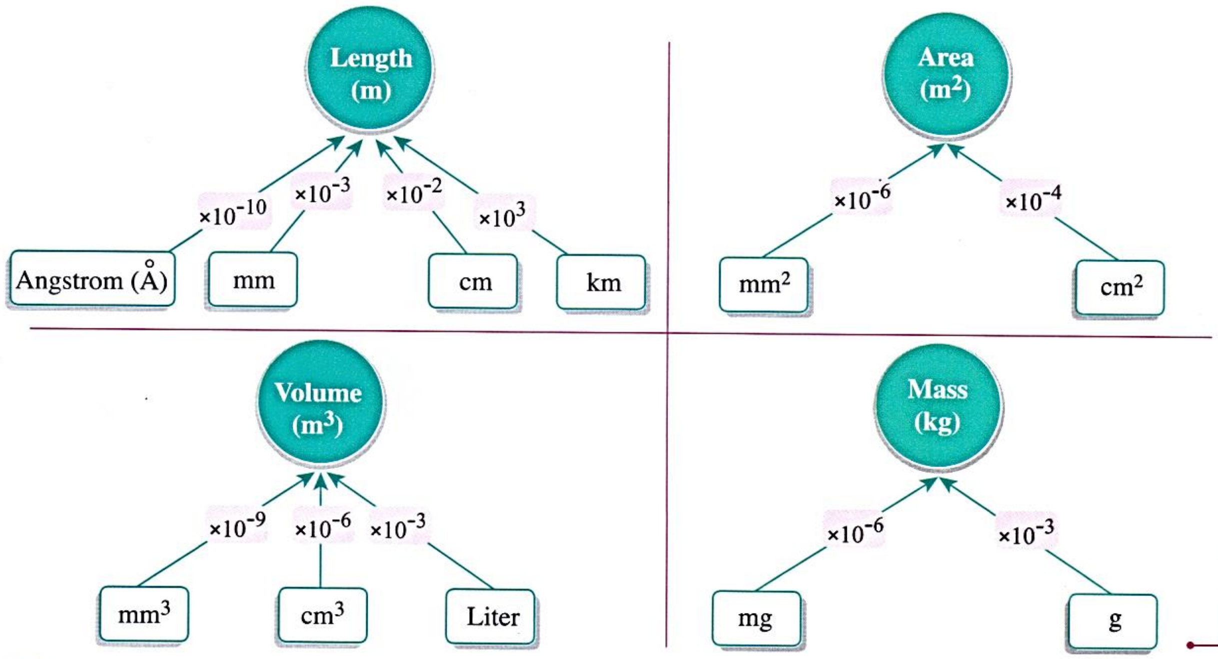
Important physical and mathematical basics

1 Common SI prefixes

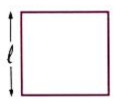
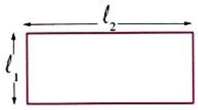
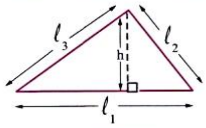
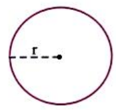
Prefix	Abbreviation	Meaning
Femto	f	10^{-15}
Pico	p	10^{-12}
Nano	n	10^{-9}
Micro	μ	10^{-6}
Milli	m	10^{-3}
Centi	c	10^{-2}
Deci	d	10^{-1}
Kilo	k	10^{3}
Mega	M	10^{6}
Gega	G	10^{9}
Tera	T	10^{12}

2 Conversions of some units

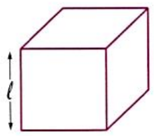
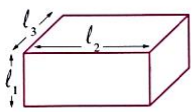
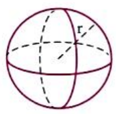
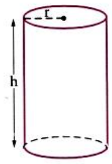


3 Perimeters, areas and volumes of some geometric shapes

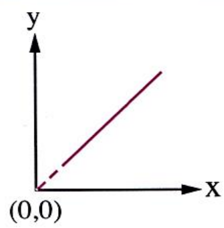
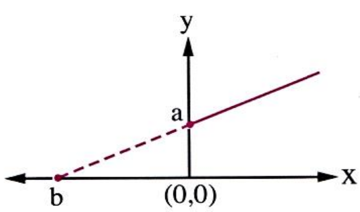
A. Plane geometric shapes :

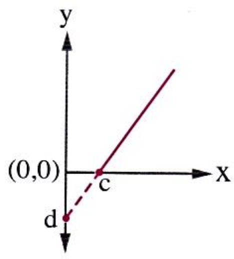
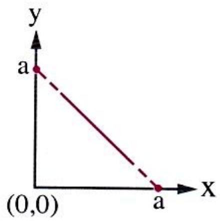
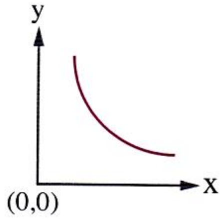
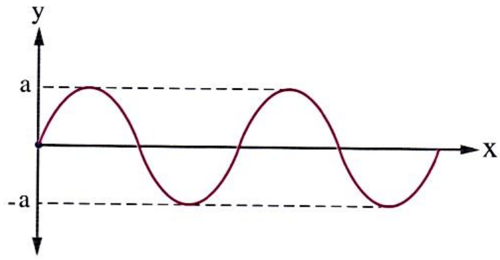
Figure	Square	Rectangle	Triangle	Circle
Geometrical shape				
Perimeter	$4\,\ell$	$2\,(\ell_1 + \ell_2)$	$\ell_1 + \ell_2 + \ell_3$	$2\,\pi r$
Area (A)	ℓ^2	$\ell_1 \times \ell_2$	$\frac{1}{2}\,\ell_1 \times h$	πr^2

B. Solid geometric shapes :

Figure	Cube	Cuboid	Sphere	Cylinder
Geometrical shape				
Volume (V)	ℓ^3	$\ell_1 \times \ell_2 \times \ell_3$	$\frac{4}{3}\,\pi r^3$	$\pi r^2 \times h$

4 Graphical representations of some relations between two variables

Relation	Graph
$y = mx$ - At x = zero $\Rightarrow$ y = zero * The straight line passes by the origin (0 , 0) **Slope** $= \frac{\Delta y}{\Delta x} = m$	
$y = a + mx$ - At x = zero $\Rightarrow$ y = a (positive value) * The straight line intersect y-axis at point (a). - At y = zero , x = b (negative value) $= -\frac{a}{m}$ **Slope** $= \frac{\Delta y}{\Delta x} = m$	

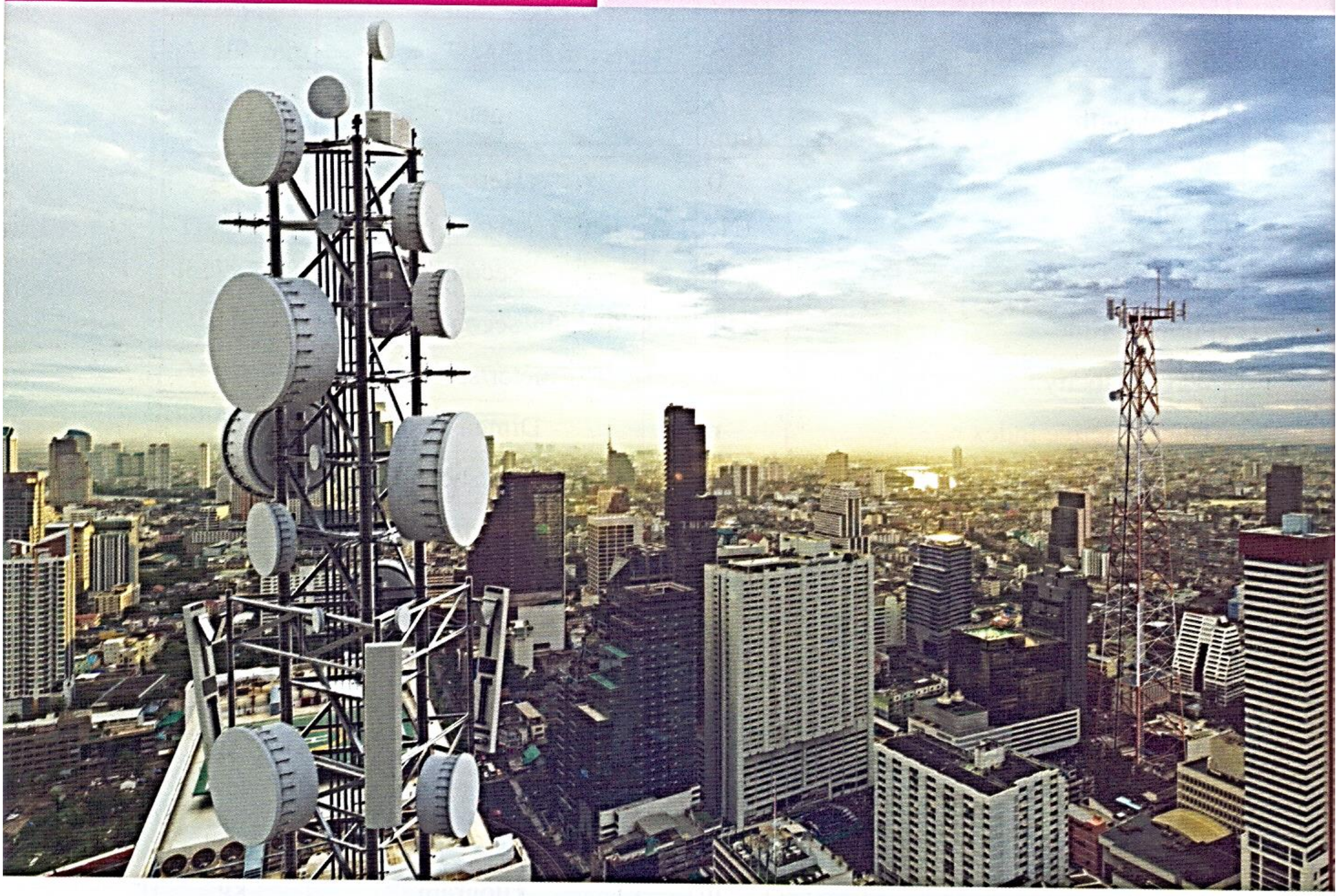
$y = mx - d$ - At y = zero $\Rightarrow x = \frac{d}{m} = c$ (positive value) * The straight line intersect x-axis at point (c). - At x = zero $\Rightarrow$ $y = -d$ (negative value) **Slope = $\frac{\Delta y}{\Delta x} = m$**	
$y = a - x$ - The sum of the two quantities x, y at any point = constant value (a) - At x = zero $\Rightarrow$ y = a (constant value) - At y = zero $\Rightarrow$ x = a (constant value) **Slope = $\frac{\Delta y}{\Delta x} = -1$**	
$y = \frac{a}{x}$ - The product of two quantities x, y at any point equals constant value (a).	
$y = a \sin(x)$ - The value of (y) varies between (a , – a) regularly with the change of x.	

The used physical quantities, their symbols and units of measurement

Physical quantity	Symbol	Unit of measurement	
Displacement or distance	d	meter	m
Amplitude	A	meter	m
Wavelength	λ (lamda)	meter	m
Frequency	υ (Neo)	Hertz = second^{-1}	Hz = s^{-1}
Time	t	second	s
Periodic time	T	second	s
Wave velocity	v	meter/second	m/s
The refractive index	n	Dimensionless quantity	
Speed of light in space	c	meter/second	m/s
Angle of incidence	ϕ	degree	deg
Angle of reflection or refraction	θ	degree	deg
Critical angle	ϕ_c	degree	deg
The apex angle of the prism	A	degree	deg
Angle of deviation	α	degree	deg
Minimum angle of deviation	α_o	degree	deg
Dispersive power of the prism	ω_α	Dimensionless quantity	
Mass	m	kilogram	kg
Volume	V_{ol}	meter^3	m^3
Density	ρ	kilogram/meter^3	kg/m^3
Force	F	Newton = kilogram.meter/second^2	N = kg.m/s^2
Area	A	meter^2	m^2
Free fall acceleration	g	meter/second^2	m/s^2
Viscosity coefficient	η_{vs}	Newton.second/meter^2 = kilogram/meter.second	N.s/m^2 = kg/m.s
Mass flow rate	Q_m	kilogram/second	kg/s
Volume flow rate	Q_v	meter^3/second	m^3/s

UNIT 1

Waves



Chapter 1 Wave Motion.

Chapter 2 Light.

Chapter 1 Wave Motion

Chapter objectives By the end of this chapter, the student will be able to :

- Recognize the meaning of wave motion.
- Mention the types of waves.
- Identify the conditions for obtaining mechanical waves.
- Recognize the concept of complete oscillation, amplitude, frequency and periodic time.
- Carry out experiments to represent the nature of transverse waves and longitudinal waves.
- Compare between transverse and longitudinal waves.
- Deduce the relation between speed of propagation, frequency and wavelength of a wave.
- Compare between mechanical and electromagnetic waves.
- Acquire the skill to solve problems using the mathematical relations in this chapter.

Chapter 1
Lesson One
Oscillatory Motion

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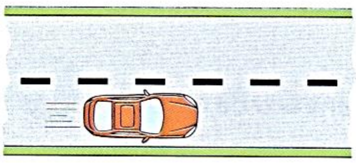
⊙ **Motion can be classified into two types :**

① Translational motion	② Periodic motion
A motion that has a starting point and a different end point.	A motion that is repeated regularly in equal intervals of time.

Examples

▸ Motion in a straight line :



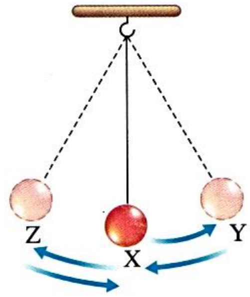
▸ Motion in a curved path (Projectile motion) :

▸ Oscillatory motion :

▸ Wave motion :

- In this chapter, we will study the wave motion, but first, we have to discover some important concepts through studying the oscillatory motion.

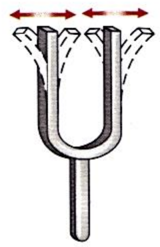
Oscillatory motion



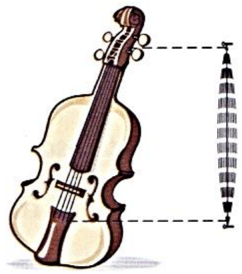
When a bob (suspended weight) of a pendulum is displaced sideways its resting position (at point X) , it will be subjected to a restoring force due to gravity, therefore when releasing the pendulum, it vibrates back and forth on the sides (Y , Z) of its equilibrium position and repeats its motion in regular time intervals, this motion is called **oscillatory motion**.

⊙ Examples of oscillatory motion :

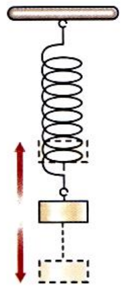
Simple pendulum (Clock pendulum)



Vibrating tuning fork



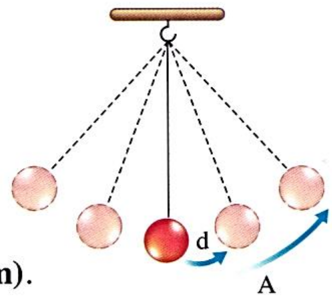
Vibrating string (Violin strings)



Plumb or bob suspended to a spring (Yoyo)

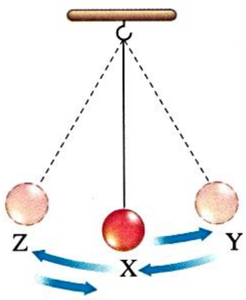
- To study oscillatory and wave motions we must know some initial terms and concepts, these physical concepts will be explained using simple pendulum.

Displacement of a vibrating motion



- When a pendulum is oscillating, its bob moves sideways its rest position where the distance that the pendulum makes from the rest position at any moment is called a **displacement (d)**.
- **Displacement** is a vector quantity which is measured in **meters (m)**.

Amplitude



- When the weight of the pendulum is displaced from point X to point Y and left to oscillate;

  1. The velocity of the pendulum at point X reaches its maximum value and at point Y and Z becomes zero.

  2. The maximum displacement of the pendulum away from its equilibrium position (XY and XZ) is called the **amplitude (A)**.

- **Amplitude** is a scaler quantity which is measured in **meters (m)**.

Complete oscillation

- When the pendulum moves from X to Y and returns to X then moves to Z and returns back again to X ($X \longrightarrow Y \longrightarrow X \longrightarrow Z \longrightarrow X$), hence the pendulum passed by X two successive times in the same direction with the same velocity, i.e. the body had the same phase when it passed by the same point for the second time. So, the pendulum has made a **complete oscillation**.

Periodic time

- The time taken by the pendulum to pass by the same point two successive times in one direction (to make a complete oscillation) is called the **periodic time**.
- Periodic time (the time of a complete oscillation) = 4 × Time of amplitude
- The periodic time (T) can be determined from the relation :

$$T = \frac{t \text{ (Time in seconds)}}{N \text{ (Number of complete oscillations)}}$$

- **Periodic time** is measured in **seconds (s)**.

Frequency

- Frequency (υ) is the number of complete oscillations per second.
- Frequency (υ) can be determined from the relation :

$$\upsilon = \frac{N \text{ (Number of oscillations)}}{t \text{ (Time)}}$$

- **Frequency** is measured in **Hertz (Hz)** which is equivalent to oscillations/second, cycles/second or second^{-1} (s^{-1}) .

The relation between frequency (υ) and periodic time (T)

$$\because \upsilon = \frac{N \text{ (Number of oscillations)}}{t \text{ (Time)}} \quad , \quad T = \frac{t \text{ (Time)}}{N \text{ (Number of oscillations)}}$$

$$\therefore \boxed{\upsilon = \frac{1}{T}} \quad \textbf{Or} \quad \boxed{T = \frac{1}{\upsilon}}$$

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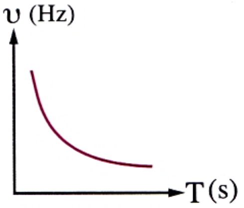
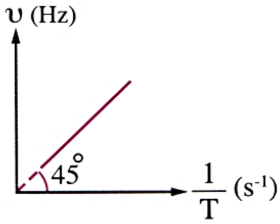
$$\therefore \boxed{\upsilon = \frac{1}{T}} \quad \textbf{Or} \quad \boxed{T = \frac{1}{\upsilon}}$$

i.e. Frequency = The reciprocal of the periodic time

So, frequency is inversely proportional to periodic time.





$$\text{Slope} = \frac{\Delta \upsilon}{\Delta \left(\frac{1}{T}\right)} = 1$$

Example

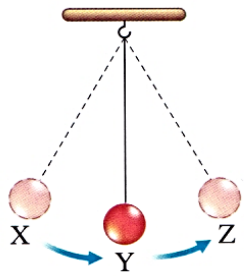
In the opposite figure : If the time taken by the pendulum to move from X to Z is 0.8 s, calculate :

(a) The periodic time.

(b) The frequency.

(c) The number of complete oscillations through 16 s.

(d) The time required to make 50 oscillations.



Solution

(a) $T = \frac{t}{N} = \frac{0.8}{\frac{1}{2}} = 1.6 \text{ s}$

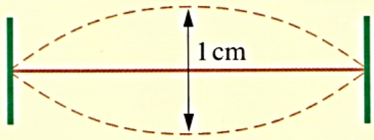
(b) $\upsilon = \frac{1}{T} = \frac{1}{1.6} = 0.625 \text{ Hz}$

(c) $N = \frac{t}{T} = \frac{16}{1.6} = 10$ oscillations

(d) $t = NT = 50 \times 1.6 = 80 \text{ s}$

1 Test yourself

The opposite figure shows a vibrating string that takes 0.01 s to reach a maximum displacement away from its rest position, calculate the amplitude and the frequency of the string.



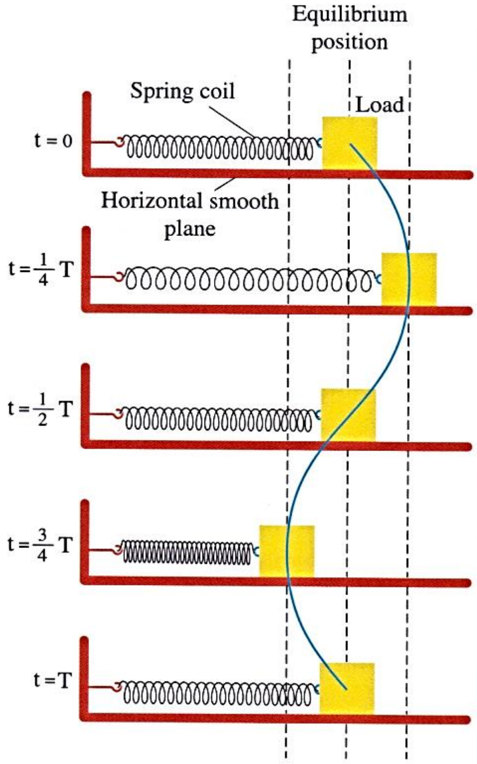
....

....

....

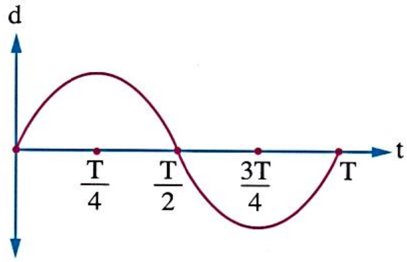
Note :

- The simple oscillatory motion (such as the motion of simple pendulum or spring coil) is called **simple harmonic motion**, which can be represented by a sinusoidal curve (sine wave) as follows :
  - **(1)** Put a load on a horizontal smooth plane and attach one end of a spring to the load and the other end to the wall.
  - **(2)** At pulling the load to the right, the spring elongates.
  - **(3)** When you release the load, it returns to the equilibrium position.
  - **(4)** Then the spring compresses.
  - **(5)** Then the load returns again to the equilibrium position. This motion is repeated in equal intervals of time.



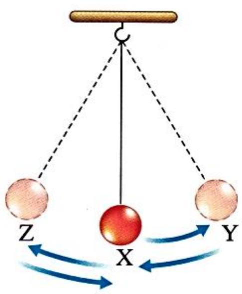
sine wave for the simple harmonic motion

- So the simple harmonic motion can be represented by a sine wave function as shown in the opposite graph :



Energy transformations during the motion of simple pendulum

1. During the pendulum motion from X to Y, its vertical height increases gradually with respect to the equilibrium position and hence its potential energy increases and its kinetic energy decreases where kinetic energy converts gradually into potential energy according to the law of conservation of energy which states that the summation of kinetic energy and potential energy (the mechanical energy) remains constant at any point along the path of motion.



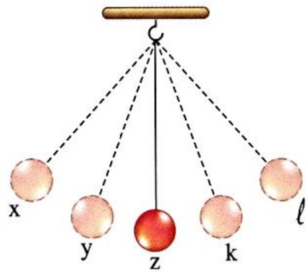
- And as the kinetic energy decreases the velocity of the pendulum decreases until it reaches zero at the highest point Y.

2. When the kinetic energy vanishes the pendulum starts to fall back in the opposite direction and moves from Y to X where its potential energy decreases gradually by the decrease of its vertical height and its kinetic energy increases which means its velocity increases until it reaches its maximum value at point X.

3. The pendulum continues its motion from X to Z due to its kinetic energy which decreases and converts to potential energy, where the potential energy increases until the pendulum reaches point Z and so on.

Example

The opposite figure shows the motion of a simple pendulum where $xy = yz = zk = k\ell$. If the pendulum takes time t to move from x to y, the periodic time is ....



ⓐ 8 t
ⓑ less than 8 t
ⓒ greater than 8 t
ⓓ indeterminable

Solution

Clue

*The pendulum moves from x to z with positive acceleration where its velocity increases as it goes down due to the change of its potential energy into kinetic energy, where its average velocity through the displacement yz is greater than through the displacement xy, so the displacement yz takes time less than t and the same for displacement zk, so the time taken to cover the distance xy is greater than half the time of the amplitude **i.e.** it is greater than $\frac{1}{8}$ the time of complete oscillation.*

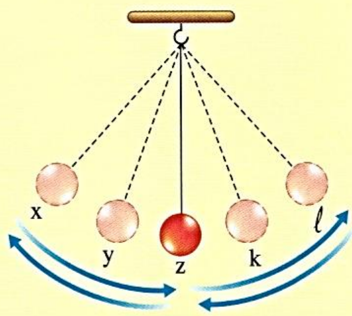
ⓑ the periodic time for the pendulum is less than 8 t

2 Test yourself

Choose :

The opposite figure shows the motion of a simple pendulum.

If : $xy = yz = zk = k\ell$, so ....



ⓐ the kinetic energy at y = The kinetic energy at k
ⓑ the potential energy at ℓ < The potential energy at y
ⓒ the kinetic energy at k > The potential energy at x
ⓓ the kinetic energy equals the potential energy at all points.

QUESTIONS ON

Chapter 1

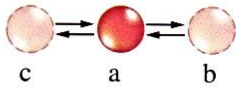
LESSON ONE

Oscillatory Motion

Interactive test

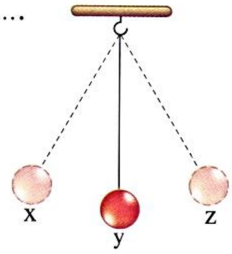
First Multiple choice questions

1 In the opposite figure, a body moves in an oscillatory motion, so the distance which is moved by the body during a complete oscillation equals ....



(a) double the distance ab
(b) double the distance bc
(c) half the distance ac
(d) four times the distance bc

2 In the opposite figure the pendulum makes a complete oscillation when ....

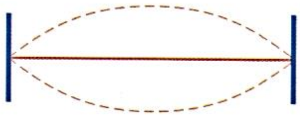


(a) it moves from x to z two times
(b) it moves from x to y four times
(c) it passes through point x two successive times in the same direction
(d) it passes through point y three times in the same direction

3 The ratio between the time of an amplitude and the time of a complete oscillation is ....

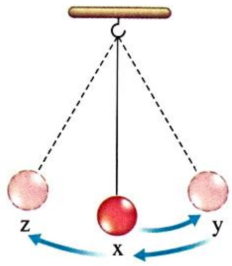
(a) $\frac{2}{1}$
(b) $\frac{1}{2}$
(c) $\frac{4}{1}$
(d) $\frac{1}{4}$

4 The opposite figure shows the motion of a vibrating string which has a periodic time T, so the time taken by the string to reach the maximum displacement from its equilibrium position is ....



(a) $\frac{T}{4}$
(b) $\frac{T}{3}$
(c) $\frac{T}{2}$
(d) T

5 The opposite figure shows a simple pendulum, if its bob has moved from position x to position y then to position z, the magnitude of the displacement of the pendulum bob equals ....



(a) A
(b) 2A
(c) 3A
(d) zero

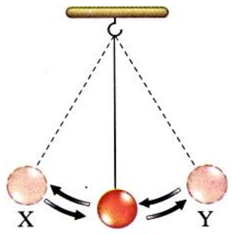
6 If a vibrating object makes 90 oscillations in one minute, then its frequency equals ....

(a) 90 Hz
(b) 60 Hz
(c) 1.5 Hz
(d) 0.6 Hz

7 If a vibrating object takes 0.1 s to complete one oscillation, the number of complete oscillations that is made by the object during 100 s equals .... oscillations.

(a) 10
(b) 100
(c) 1000
(d) 10000

8 In the opposite figure : If the pendulum takes 1 s to move between X and Y, so its frequency equals ....



(a) 0.5 Hz (b) 5 Hz
(c) 10 Hz (d) 50 Hz

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9 Simple pendulum takes 0.01 s to reach the maximum displacement from the equilibrium position, so its frequency equals ....

(a) 20 Hz (b) 25 Hz (c) 50 Hz (d) 100 Hz

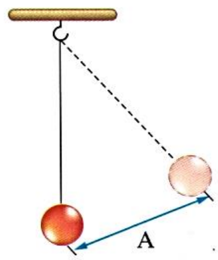
---

10 The ratio between the periodic time and the frequency of a vibrating body equals $\frac{1}{625}$ s^2, so the number of oscillations made by the body during 25 s is .... oscillations.

(a) 25 (b) 125 (c) 425 (d) 625

---

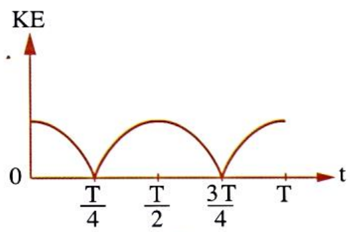
11 In the opposite figure : If the time taken by the pendulum to move from the equilibrium position to $\frac{A}{2}$ is t_1 and the time taken by the pendulum to move from $\frac{A}{2}$ to A is t_2, so ....



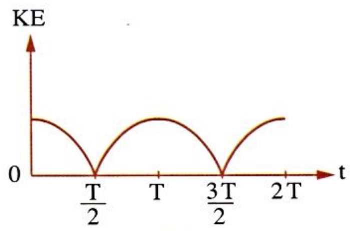
(a) $t_1 = t_2$ (b) $t_1 > t_2$
(c) $t_1 < t_2$ (d) the answer is indeterminable

---

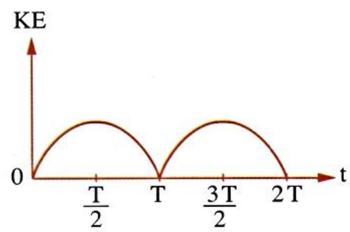
12 A simple pendulum started a simple harmonic motion from the farthest position away from its equilibrium position at t = 0. If the periodic time of the pendulum is T, which of the following graphs represents its motion ? ....



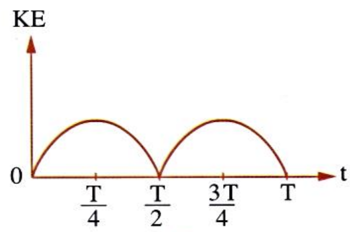
(a)



(b)



(c)

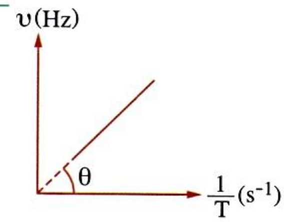


(d)

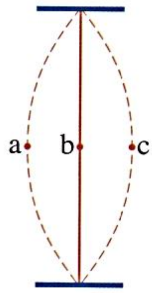
Second Essay questions

1. **What happens** to the periodic time of a vibrating object when its frequency triples? **Explain your answer**.

2. The opposite graph represents the relation between the frequency of an oscillatory motion and the reciprocal of its periodic time (where the two coordinates have the same scale). **What** is the value of angle θ ?



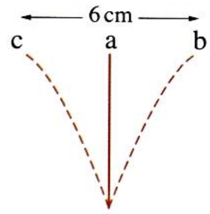
3. The opposite figure shows the motion of a vibrating string :
   (a) **At which point** is the velocity of the string maximum?
   (b) **At which point** is the potential energy of the string maximum?
   (c) **Compare between** the time of the string motion from b to c and the time of its motion from b to a.



Third Problems

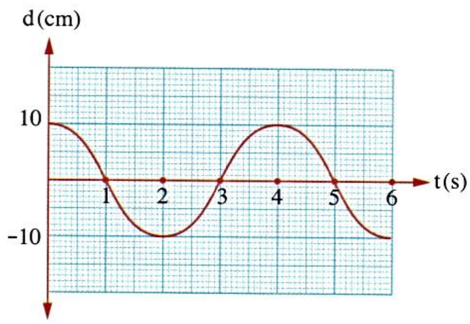
1. A wave generator produces 16 waves in 4 s, **calculate :**
   (a) The frequency. (b) The periodic time. (4 Hz, 0.25 s)

2. **In the opposite figure,** a flexible oscillating rod takes time 0.01 s to move from a to b,
   calculate :
   (a) The periodic time. (b) The frequency. (c) The amplitude.



(0.04 s , 25 Hz, 3 cm)

3. The opposite graph represents the relation between the displacement of a body which makes a simple harmonic oscillation and time,
   find :
   (a) The amplitude of the body.
   (b) The periodic time of its motion.



(10 cm, 4 s)

4. A simple pendulum makes 90 oscillations in one minute where it covers a distance 20 cm during each oscillation, **calculate :**
   (a) The amplitude. (b) The frequency. (c) The periodic time. (5 cm , 1.5 Hz , 0.67 s)

Chapter 1

Lesson Two

Wave Motion

⊙ When a stone is dropped into water (as in the figure) :

- The collision of the stone with water becomes a source of disturbance.
- This disturbance propagates on the surface of water in a shape of uniform concentric circles, whose center is the position at which the stone falls.
- These circles transfer energy in the same direction of their propagation.

Water waves

- These circles are called water waves and its propagation represents a wave motion. Hence we can define the wave as a disturbance that propagates and transfers energy in the direction of propagation.

Types of waves

- Many forms of waves exist around us, some waves can be seen such as water waves, other waves cannot be seen but we can detect them such as radio and X-ray waves.
- **Waves can be classified as the following :**

Waves

1. **Mechanical waves**
   - Transverse waves — *Example*: Water waves
   - Longitudinal waves — *Example*: Sound waves
2. **Electromagnetic waves**
   - Transverse waves — *Example*: Radio waves

First Mechanical waves

Source :

Mechanical waves are produced due to the vibration of a body in a medium, so the vibration (disturbance) around the body propagates through the medium.

Propagation medium :

They need a medium through which they can propagate.

Examples :

- Water waves.
- Sound waves.
- Waves that propagate in strings during its vibration.

Conditions of producing mechanical waves

1. **The existence of a vibrating source :**
   Like dropping a pebble in still water, pulling a string, pushing a pendulum or hitting a tuning fork.
2. **The occurrence of a disturbance that transfers from the source to the medium :**
   Like the formed ripples when a pebble is dropped into the water which propagate as concentric circles.
3. **The existence of a medium to transmit the disturbance :**
   Mechanical waves (like sound waves) need a medium through which they can travel because the molecules of the medium vibrate and collide with each other without moving away from their positions to transfer the mechanical energy of the wave, thus :

- We can't hear the voices of cosmic explosions that happen in space.
- Astronauts use wireless devices to communicate with each other in space.

Types of mechanical waves

1. Transverse waves.
2. Longitudinal waves.

1 Transverse waves

To describe the nature of transverse waves, we carry out the following experiment :

Experiment 1

Steps and observations :

1. Bring a long rope and fix its end to a vertical wall.
2. Hold the other end of the rope with your hand.
3. Move the end of the rope with your hand up and return it to the original position once.

   Observation : A pulse wave is generated through the rope (figure (1)).

Figure (1)

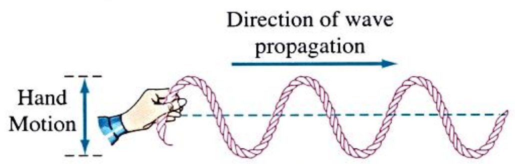


Figure (2)

4. Continue in moving the end of the rope up and down.

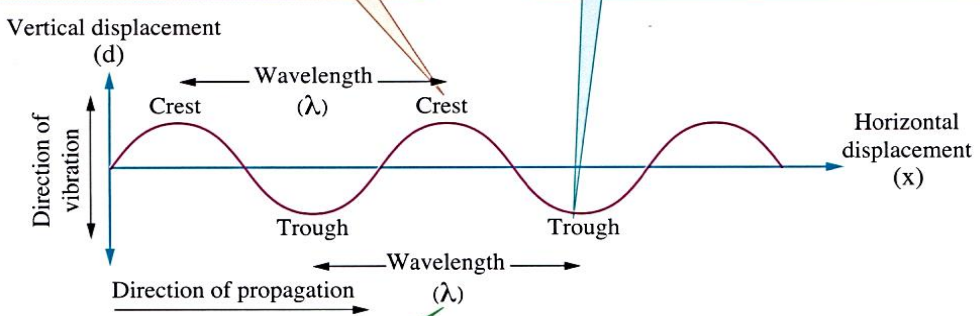
   Observation : The end of the rope moves upwards and downwards in a simple harmonic motion that transfers along the rope as continuous waves (transverse wave train) which are called travelling waves (figure (2)).

Conclusion :

When the rope vibrates upwards and downwards, a wave transfers in the rope in which the molecules of the medium (rope) vibrate about their equilibrium positions in a direction perpendicular to the direction of the wave propagation. This wave is called a transverse wave which consists of crests and troughs as shown in the following figure :

The position that represents the maximum displacement for the molecules of the medium in the positive direction (positive pulse).

The position that represents the maximum displacement for the molecules of the medium in the negative direction (negative pulse).

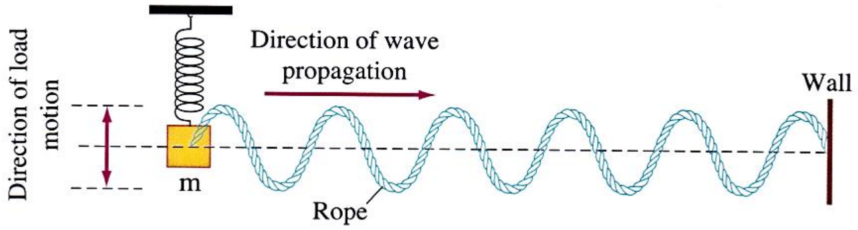


The distance between two successive crests or two successive troughs or any two successive points along the direction of propagation that are in the same phase is called **the wavelength of the transverse wave (λ)**.

Examples : - Vibrating strings waves. - Water surface waves.

Notes :

1. Transverse waves can be obtained by using a load attached to a vertical spring, to let the load vibrate up and down about its equilibrium position, and a horizontal rope whose other end is fixed to a vertical wall, as the following figure :



2. The work done by the vibrating source (vibration generator or the hand) on the string travels in the form of :

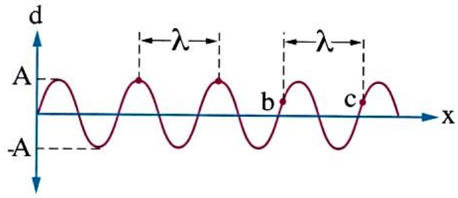
- Potential energy represented in the tension of the string.
- Kinetic energy represented in the vibration of the string.

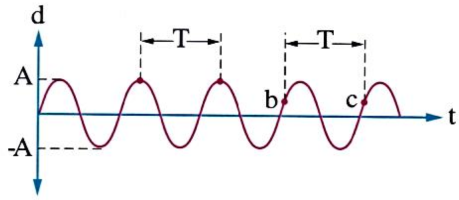
Graphical representation of transverse waves

At plotting the relation between

The displacement of the molecules of the medium (d) and the horizontal distance (x) at a certain instant.	The displacement of one of the medium molecules (d) and time (t).

We get a sine curve





From the two graphs we find :

(1) The amplitude of the wave (A) = The maximum displacement of the molecules of the vibrating medium away from their equilibrium positions.

(2) The two points b and c are successive and in the same phase :

∴ The distance between **b** and **c** = Wavelength	∴ The time interval between **b** and **c** = Periodic time

$\frac{t}{T}$

Which is determined from the relation :

$$\lambda = \frac{x \text{ (Total distance)}}{N \text{ (Number of waves)}}$$

Which is determined from the relation :

$$\upsilon = \frac{N \text{ (Number of waves)}}{t \text{ (Time in seconds)}}$$

Example 1

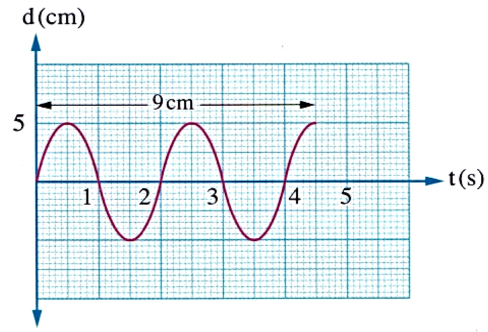
The opposite graph represents a transverse wave, calculate :

(a) The amplitude.

(b) The frequency.

(c) The periodic time.

(d) The wavelength.



Solution

(a) A = 5 cm

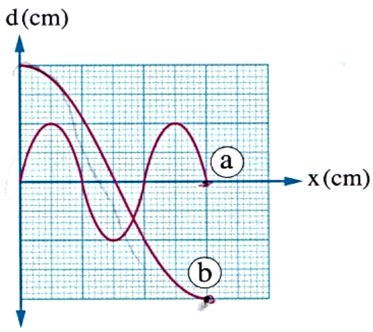
(b) $\upsilon = \frac{N}{t} = \frac{2.25}{4.5} = 0.5$ Hz

(c) T = 2 s

(d) $\lambda = \frac{x}{N} = \frac{9}{2.25} = 4$ cm

Example 2

The opposite graph represents two transverse waves, find the ratio between their wavelengths $\frac{\lambda_a}{\lambda_b}$.



Solution

Clue

From the graph we find that when the two waves cover the same distance, wave (a) makes 1.5 complete waves and wave (b) makes 0.5 complete wave.

$\because \lambda = \frac{x}{N}$

$\therefore \frac{\lambda_a}{\lambda_b} = \frac{N_b}{N_a} = \frac{0.5}{1.5} = \frac{1}{3}$

Test yourself

The opposite graph represents a transverse wave, **calculate :**

(a) The periodic time.

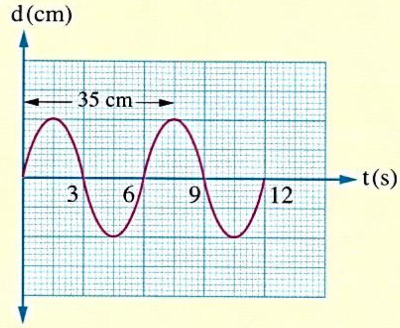
(b) The frequency.

(c) The wavelength.

....

....

....



2 Longitudinal waves

To describe the nature of longitudinal waves, we carry out the following experiment :

Experiment 2

Steps and observations :

1. Put a load m on a smooth horizontal plane and attach the load between two springs, one of them is longer than the other and each of them is attached to a wall (figure (1)).

2. Pull the load a distance x to the right side then leave it to return to the equilibrium position (figure (2)).

Observation : The spring compresses in the right side and the compression transfers consecutively through the spring.

3. Pull the load a distance x to the left side then leave it to return to the equilibrium position (figure (3)).

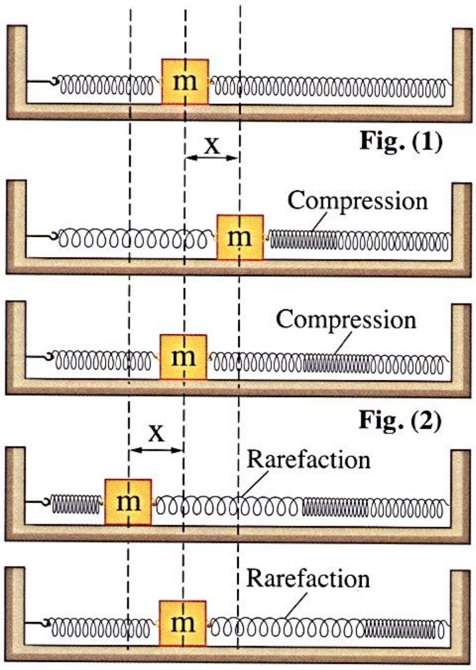
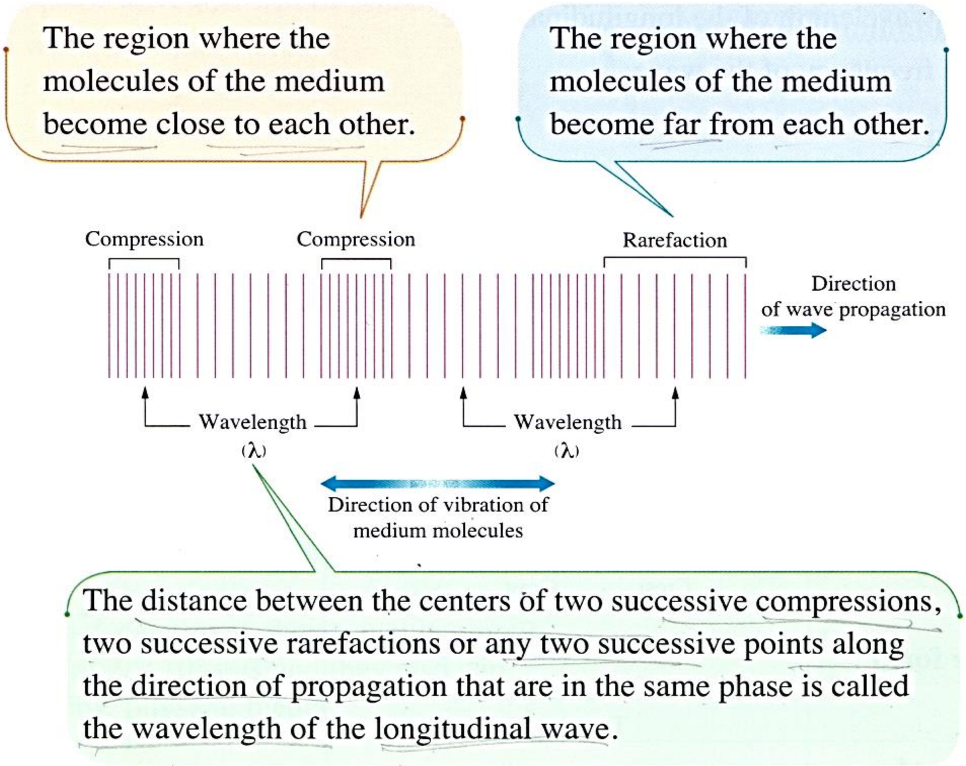


Fig. (1) **Fig. (2)** **Fig. (3)**

Observation : The spring rarefies in the right side and the rarefaction transfers consecutively through the spring.

Conclusion :

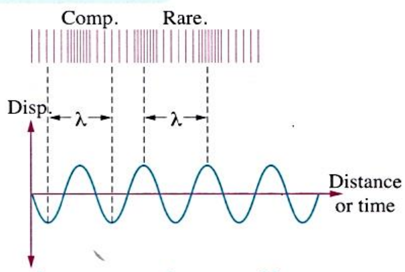
- During the vibration of the load, a wave propagates in the spring where the direction of vibration of the medium particles is along the same line of the wave propagation, such wave is called longitudinal wave and it consists of a group of compressions and rarefactions which transfer along the spring as the following figure :



Examples : - Sound waves in gases. - Waves inside water.

Graphical representation of longitudinal waves

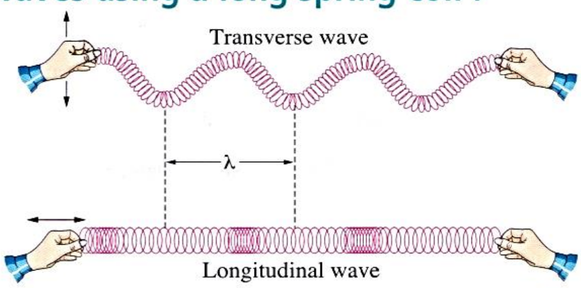
⊙ When we plot the relation between the displacement and the distance or between the displacement and the time, we get a sine wave curve.
So, all the concepts and laws of the transverse wave are applicable to this curve.



☆ How to get transverse and longitudinal waves using a long spring coil :

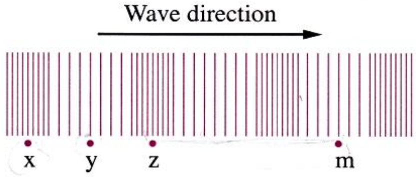
When fixing a spring coil from one of its ends while moving the other end of the coil :

1. Up and down, a transverse wave is formed as shown in the figure.
2. Back and forth, a longitudinal wave is formed as shown in the figure.



Example

The opposite figure represents a longitudinal wave. If the distance between x and y is 1.7 m and the time between z and m is 0.015 s , calculate :



(a) The wavelength of the longitudinal wave.

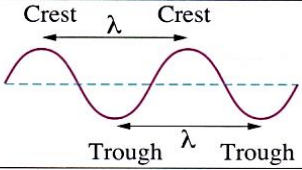
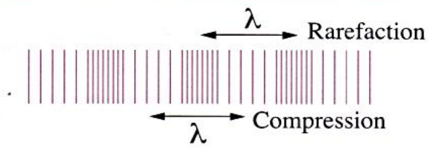
(b) The frequency of the wave.

Solution

(a) $\lambda = \frac{x}{N} = \frac{1.7}{0.5} = 3.4 \text{ m}$

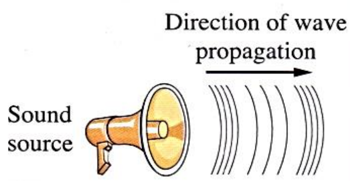
(b) $\upsilon = \frac{N}{t} = \frac{1.5}{0.015} = 100 \text{ Hz}$

➲ **From the previous, we can compare between the two types of mechanical waves (transverse and longitudinal) as follows :**

Points of Comparison	Transverse wave	Longitudinal wave
Wave form :		
Direction of vibration of medium particles :	Perpendicular to the direction of wave propagation.	Along the line of wave propagation.
Composition :	Crests and troughs	Compressions and rarefactions
Wavelength :	The distance between two successive crests or two successive troughs.	The distance between the centers of two successive compressions or the centers of two successive rarefactions.
Examples :	• Propagating waves in strings. • Waves on water surface.	• Sound waves in gases. • Waves inside water.

Note :

- Sound propagates in gases in the form of longitudinal waves because when the source vibrates, the gas (medium) particles vibrate and displace along the line of wave propagation in the form of compressions and rarefactions due to the weak attraction forces of the medium particles.



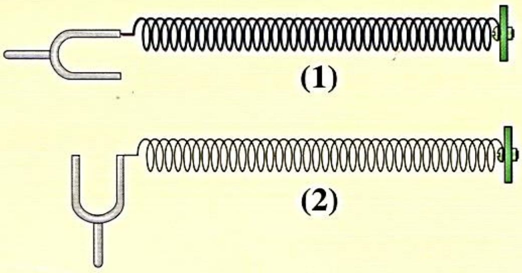
4 Test yourself

The opposite figures show two tuning forks attached to two springs.

What is the type of wave that will be produced in each case when the forks vibrate ?

....

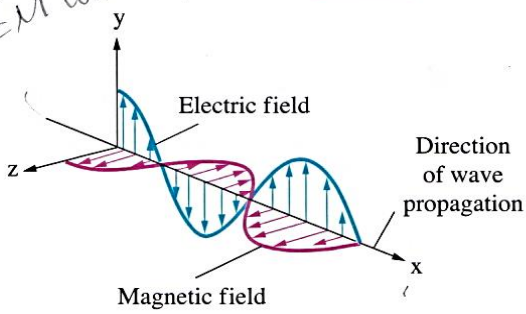
....



Second Electromagnetic waves

Electromagnetic waves :

They are waves that originate from the vibration of electric and magnetic fields where both fields are in the same phase perpendicular to each other and to the direction of their propagation.



Propagation : They don't require a medium through which they can travel, they travel in empty space at a speed of 3×10^8 m/s and they also can travel through some physical media.

Examples :

- Light waves.
- X-ray waves (which are used in medical diagnosis).
- Gamma rays.
- Wireless waves (radio , TV and cell phones).

Types : Transverse waves only.

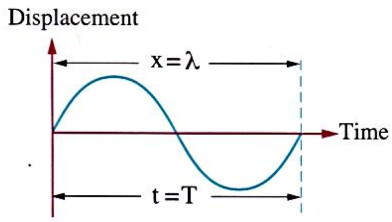
From the previous, we can compare between mechanical and electromagnetic waves as follows :

Points of Comparison	Mechanical waves	Electromagnetic waves
Definition :	Waves originated from the vibration of medium particles either perpendicular to the direction of wave propagation or along the line of the wave propagation.	Waves originated from the vibration of electric and magnetic fields perpendicular to the direction of the wave propagation.
Propagation :	They require a medium through which they can propagate.	They don't require a medium to propagate, so they can travel through empty space.
Types :	Transverse and longitudinal waves	Transverse waves only
Examples :	• Water waves. • Sound waves. • Propagating waves in strings.	• Radio waves. • Light waves. • X-ray waves.

Deduction of the speed of propagation of the waves : (the relation between wavelength, frequency and the speed of propagation of the waves) :

- If a wave travels at speed v for a distance that equals its wavelength (λ), the wave takes time equals the periodic time (T).

Wave speed (v) :
It is the distance travelled by the wave in one second in the direction of propagation.



$\because v = \frac{x}{t}$ when : $x = \lambda$, $t = T$ $\therefore v = \frac{\lambda}{T}$

$\because \upsilon = \frac{1}{T}$ $\therefore \boxed{v = \lambda\upsilon}$

The factors that affect the speed of a wave in a medium :

It depends on the type of the medium only and does not depend on the frequency or wavelength.

Notes :

- The relation ($v = \lambda\upsilon$) is applied to all types of waves (mechanical and electromagnetic).

- When two waves (for example : two sound waves) propagate in the same medium , their speeds are the same because the wave speed depends only on the medium type.

$$v_1 = v_2$$
$$\lambda_1\upsilon_1 = \lambda_2\upsilon_2$$

- Where λ_1 and υ_1 are the wavelength and the frequency for the first wave, λ_2 and υ_2 are the wavelength and the frequency for the second wave.

$$\therefore \boxed{\frac{\lambda_1}{\lambda_2} = \frac{\upsilon_2}{\upsilon_1}}$$

- When a wave (sound or light) transfers from one medium to another medium, its frequency remains constant because the wave frequency depends on the source.

$$\upsilon_1 = \upsilon_2$$
$$\frac{v_1}{\lambda_1} = \frac{v_2}{\lambda_2}$$

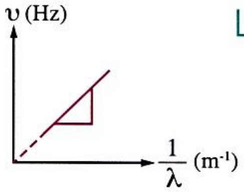
- Where λ_1 and v_1 are the wavelength and the speed for the first medium, λ_2 and v_2 are the wavelength and the speed for the second medium.

$$\therefore \boxed{\frac{\lambda_1}{\lambda_2} = \frac{v_1}{v_2}}$$

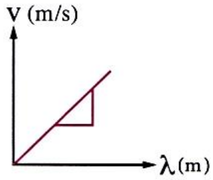
i.e.

- The wavelength is inversely proportional to the frequency at constant wave speed.
- The wave speed is directly proportional to the wavelength at constant frequency.

Graphical representation



$$\text{Slope} = \frac{\Delta \upsilon}{\Delta (\frac{1}{\lambda})} = v$$



$$\text{Slope} = \frac{\Delta v}{\Delta \lambda} = \upsilon$$

Example 1

Light waves propagate in space at a speed of 300000 km/s (3×10^8 m/s). If the wavelength of a light wave is 5000 Å, what is the frequency of this light? (given that : 1 Angstrom (Å) = 10^{-10} m)

Solution

$c = 3 \times 10^8$ m/s $\lambda = 5000$ Å

$\lambda = 5000 \times 10^{-10} = 5 \times 10^{-7}$ m

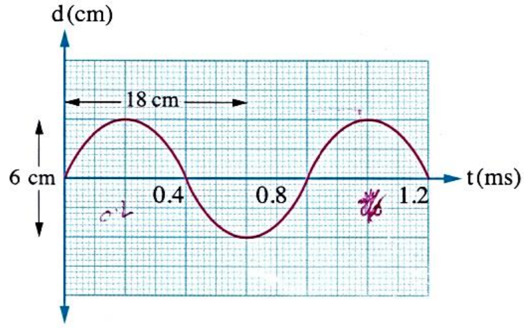
$c = \lambda \upsilon$

$3 \times 10^8 = 5 \times 10^{-7} \times \upsilon$

$$\upsilon = \frac{3 \times 10^8}{5 \times 10^{-7}} = 6 \times 10^{14} \text{ Hz}$$

Example 2

The opposite graph represents the relation between displacement (d) and time (t) for a longitudinal wave propagating in a medium. Calculate the speed of propagation of this wave in the medium.



Solution

$$\lambda = \frac{X}{N} = \frac{18}{0.75} = 24 \text{ cm}$$

$$\upsilon = \frac{N}{t} = \frac{1.5}{1.2 \times 10^{-3}} = 1250 \text{ Hz}$$

$$v = \lambda\,\upsilon = 24 \times 10^{-2} \times 1250 = 300 \text{ m/s}$$

Example 3

Two tones, whose frequencies are 340 Hz and 212 Hz, travel in air. If the wavelength of one of them is longer than the other by 60 cm, calculate the speed of sound in air.

Solution

$\upsilon_1 = 340$ Hz $\upsilon_2 = 212$ Hz

Clue

When two waves have the same speed, their wavelengths and frequencies are inversely proportional, so the longer wavelength belongs to the smaller frequency.

$$\lambda_2 = \lambda_1 + 0.6$$

$$\frac{\upsilon_1}{\upsilon_2} = \frac{\lambda_2}{\lambda_1} \quad , \quad \frac{340}{212} = \frac{\lambda_1 + 0.6}{\lambda_1}$$

$$340\,\lambda_1 = 212\,\lambda_1 + 127.2 \quad , \quad \lambda_1 = \frac{159}{160} \text{ m}$$

$$\therefore v = \upsilon_1\lambda_1 = \frac{159}{160} \times 340 = 337.875 \text{ m/s}$$

5 Test yourself

(1) If a sound wave travelled from one medium to another and the ratio between its wavelengths in the two media was $\frac{2}{3}$ respectively, **what** is the ratio between the speeds of sound in the two media respectively?

....

(2) If the ratio between the frequency of a man's voice and that of a girl's voice is $\frac{3}{4}$, **what** is the ratio between the speeds of the voices of the man and the girl in air ?

....

QUESTIONS ON

Chapter 1

LESSON TWO

Wave Motion

Interactive test

First Multiple choice questions

1 Waves transfer ....

(a) matter (b) particles (c) energy (d) water

2 Which of the following statements is not always correct for mechanical waves? ....

(a) They are formed as a result of a disturbance occurring in the medium

(b) The molecules of the medium vibrate up and down as a sine wave

(c) They transfer energy in their direction of propagation

(d) They need a medium through which they can propagate

3 If the distance between two successive points in phase for a wave equals 50 cm, then the wavelength for this wave equals ....

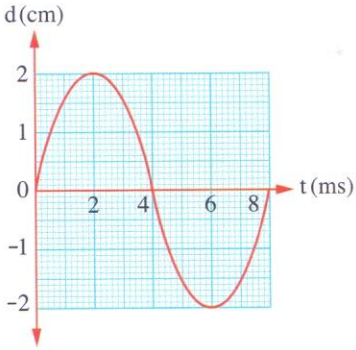
(a) 0.125 m (b) 0.25 m (c) 0.5 m (d) 1 m

4 Sound waves travel in gases as ....

(a) longitudinal waves (b) transverse waves

(c) longitudinal and transverse waves (d) electromagnetic waves

5 The opposite figure represents a transverse wave :



(i) The amplitude of this wave is ....

(a) 2 cm (b) 3 cm

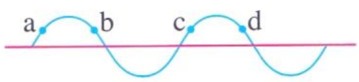
(c) 4 cm (d) 6 cm

(ii) The frequency of this wave is ....

(a) 100 Hz (b) 125 Hz

(c) 250 Hz (d) 500 Hz

6 In the opposite wave :

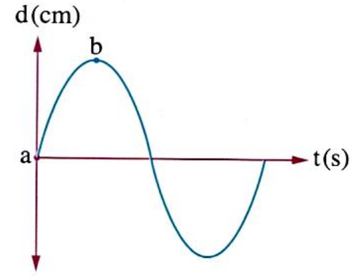


Points .... have the same phase.

(a) (a, b, c) (b) (a, b)

(c) (b, c) (d) (b, d)

7 The opposite figure represents the relation between the vertical displacement (d) of one of the medium particles and the time (t) for a transverse wave :
If the frequency of the wave equals 50 Hz, the time interval between the two points (a) and (b) is ....



ⓐ $\frac{2}{25}$ s
ⓑ $\frac{1}{25}$ s
ⓒ $\frac{1}{50}$ s
ⓓ $\frac{1}{200}$ s

---

8 If the time interval between the pass of the first crest and the tenth crest by a point in the path of a wave motion is 0.2 s, then the frequency is ....
ⓐ 45 Hz
ⓑ 50 Hz
ⓒ 55 Hz
ⓓ 60 Hz

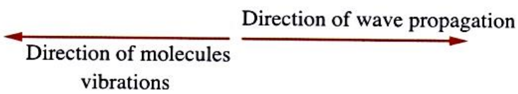
---

9 A girl dropped a stone in water pond and watched the formed waves. She found that 18 waves have collided with the edge during 10 s. If the distance between every two consecutive crests is 12 cm, so .... , ...

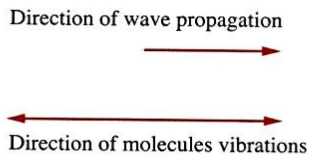
	The wavelength (cm)	The frequency (Hz)
ⓐ	24	1.8
ⓑ	24	0.6
ⓒ	12	1.8
ⓓ	12	0.6

---

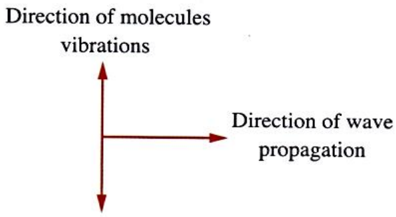
10 Which of the following figures represents the propagation of a longitudinal wave? ....



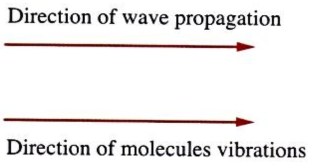
ⓐ



ⓑ

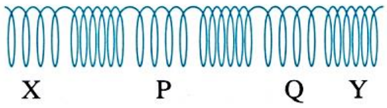


ⓒ



ⓓ

11 In the opposite figure :
A longitudinal wave propagates in a spring.
The wavelength of this wave is the distance ....



(a) PQ (b) 2 PQ (c) $\frac{XY}{2}$ (d) XY

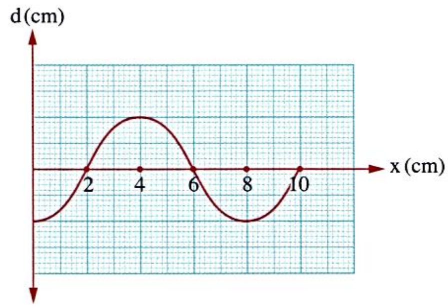
---

12 When two different tuning forks of different frequencies vibrate in air, their waves have ....

(a) different periodic time (b) different wavelengths
(c) the same speed (d) all the previous

---

13 The opposite figure represents the relation between the displacement of medium particles (d) and the propagation distance (x) for a transverse wave. If the frequency of this wave is 80 Hz, its speed equals ....



(a) 0.64 m/s
(b) 0.32 m/s
(c) 6.4 m/s
(d) 3.2 m/s

---

14 A girl stood on the beach to watch the waves. She observed that every two seconds, four waves hit a rock in front of her and each wave has a length of 0.5 m. So, the wave speed is ....

(a) 0.2 m/s (b) 0.25 m/s (c) 0.5 m/s (d) 1 m/s

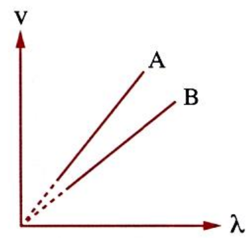
---

15 If the frequency of a wave which is moving in a medium decreased to the half, ...

(a) its wavelength would increase to the double
(b) its wavelength would decrease to the half
(c) its speed would decrease to the half
(d) its speed would increase to the double

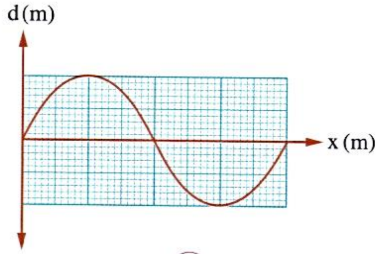
---

16 If the opposite graph shows the relation between the speed and the wavelength for two waves of the same type (A and B) when they propagate through different media , so ....

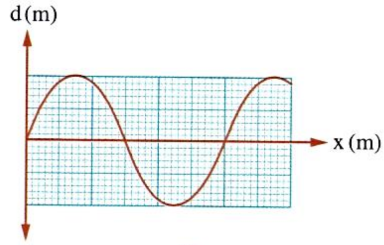


(a) $\upsilon_A > \upsilon_B$ (b) $\upsilon_A < \upsilon_B$
(c) $\lambda_A = \lambda_B$ (d) $\lambda_A > \lambda_B$

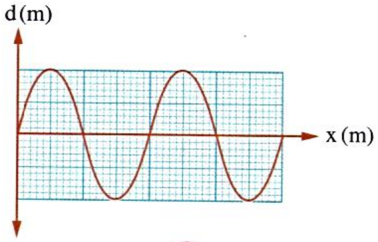
17 A transverse wave is propagating in different media and the following graphs represent the relation between the propagation distance (x) and the vertical displacement (d) of the medium particles at a certain moment with the same scale. In which media does the wave have the highest speed ? ....



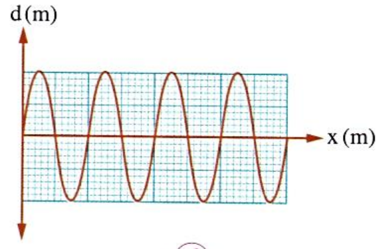
ⓐ



ⓑ

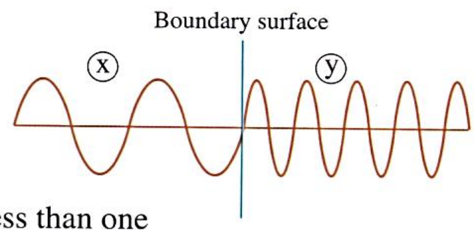


ⓒ



ⓓ

18 The opposite figure shows a wave which is travelling through medium x then it moves to another medium y, so the ratio between the speed of the wave in medium x to its speed in medium y is ....



ⓐ greater than one
ⓑ less than one
ⓒ one
ⓓ indeterminable

19 If the terminal of a spring is being moved to make a transverse wave of wavelength 30 cm and periodic time 0.1 s, then the terminal of the spring is being moved to make a longitudinal wave of periodic time 0.2 s which has the same speed as the transverse wave, so the wavelength of the longitudinal wave equals ....

ⓐ 7.5 cm ⓑ 15 cm ⓒ 30 cm ⓓ 60 cm

20 A wave of frequency υ_1 and wavelength λ_1 propagates in a medium with speed v_1, if this wave travels from this medium to another medium where its speed becomes $\frac{2}{3}v_1$, then ....

ⓐ the frequency υ_1 remains constant and the wavelength becomes $\frac{3}{2}\lambda_1$
ⓑ the frequency υ_1 remains constant and the wavelength becomes $\frac{2}{3}\lambda_1$
ⓒ the wavelength λ_1 remains constant and the frequency becomes $\frac{3}{2}\upsilon_1$
ⓓ the wavelength λ_1 remains constant and the frequency becomes $\frac{2}{3}\upsilon_1$

21 Two sound waves, whose frequencies are 512 Hz and 256 Hz, propagate in a certain medium;

(i) The ratio between their wavelengths respectively is ....

ⓐ $\frac{2}{1}$ ⓑ $\frac{1}{2}$ ⓒ $\frac{3}{1}$ ⓓ $\frac{1}{3}$

(ii) The ratio between their speeds respectively is ....

ⓐ $\frac{2}{1}$ ⓑ $\frac{1}{2}$ ⓒ $\frac{1}{1}$ ⓓ $\frac{3}{1}$

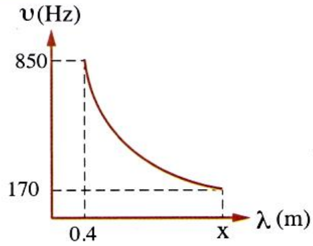
---

22 A sound wave of frequency 512 Hz travelled from air to water. If the speed of sound in air is 340 m/s and in water is 1360 m/s , so the frequency of the wave in water equals ....

ⓐ 128 Hz ⓑ 256 Hz ⓒ 512 Hz ⓓ 204 Hz

---

23 The opposite graph shows the relation between the frequency (υ) and the wavelength (λ) for different tuning forks which vibrate in air, so the value of X is ....



ⓐ 0.8 m ⓑ 1.2 m

ⓒ 1.6 m ⓓ 2 m

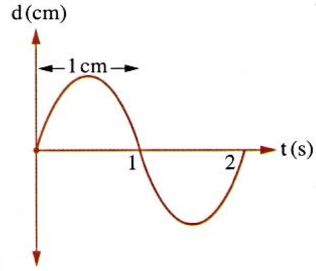
---

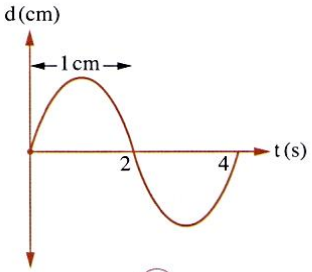
24 The vertical distance between a crest and the consecutive trough in a transverse wave equals the horizontal distance between them. If the speed of the wave is 3.2 m/s and its frequency is 16 Hz, so its amplitude equals ....

ⓐ 0.5 m ⓑ 0.2 m ⓒ 0.1 m ⓓ 0.05 m

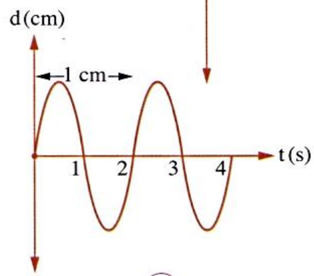
---

25 The opposite figure represents a wave that was travelling through a medium with a speed v, if the wave moved to another medium where its speed became 2 v, so the figure which represents the wave in the second medium would be ....

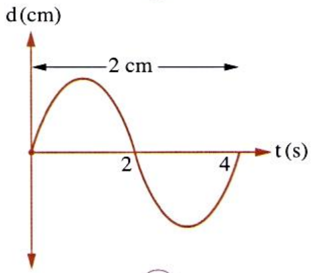




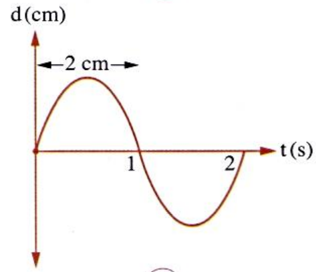
ⓐ



ⓑ



ⓒ



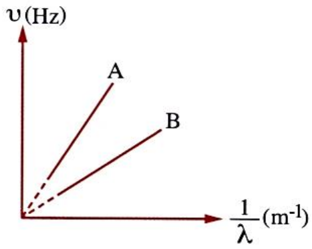
ⓓ

26 A boy heard the thunder 18.74998 s after seeing the lightening of a thunderstorm which is at a distance 6 km, so the speed of sound in air equals ....
(where : The speed of light in air = 3×10^8 m/s)

ⓐ 360 m/s ⓑ 340 m/s ⓒ 330 m/s ⓓ 320 m/s

---

27 If the opposite graph shows the relation between frequency and wavelength for a range of frequencies of ultrasonic waves through two different media (A and B) , so ....



ⓐ $v_A > v_B$ ⓑ $v_A < v_B$
ⓒ $v_A = v_B$ ⓓ not enough data for conclusions

---

28 In a sinusoidal wave, the time required for a particular point to move from maximum displacement to zero displacement is 0.17 seconds. The frequency of the wave is ....

ⓐ 1.47 Hz ⓑ 0.36 Hz ⓒ 0.73 Hz ⓓ 2.94 Hz

---

29 Which of the following statements is wrong ? ....

ⓐ Sound travels in straight lines
ⓑ Sound is a form of energy
ⓒ Sound travels in the form of waves
ⓓ Sound travels faster in vacuum than in air

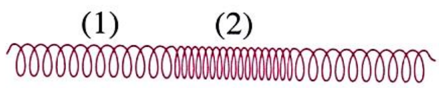
---

30 If two waves have the same frequency, what other characteristic must be the same for these waves ? ....

ⓐ Speed ⓑ Periodic time ⓒ Amplitude ⓓ Wavelength

Second Essay questions

1 The opposite figure shows a pulse moving through a spring.



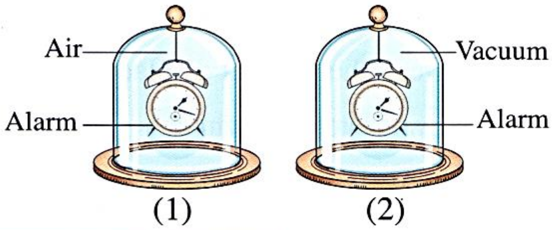
Study the figure and answer the following questions :

(a) What is the type of the produced mechanical wave in the spring?
(b) What is the direction of motion of the medium molecules with respect to the direction of wave propagation ?
(c) What are the parts (1) and (2) representing ?

---

2 In a raining day a boy notices that he sees the lightening before hearing the thunder, **explain that.**

3 Two glass jars contain two alarms. If one of them is containing air and the other is vacuumed from air, **which** of the two alarms can be heard, **and why?**



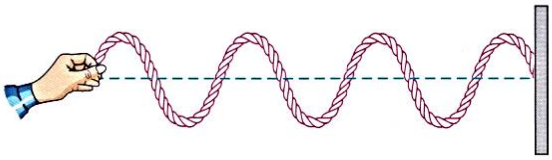
4 **Give reasons for :**

(1) Electromagnetic waves don't need a medium through which they can propagate.

(2) We see the light of the Sun and don't hear the sound of the explosions inside it.

(3) Astronauts use wireless devices to communicate on the surface of the Moon.

5 If a rope is fixed to the wall and its other terminal is being moved up and down so a wave is produced in the rope as shown in the figure, then if you moved your hand faster without changing the vertical displacement of your hand's motion or the tension force in the rope, **what happens for each of the following :**



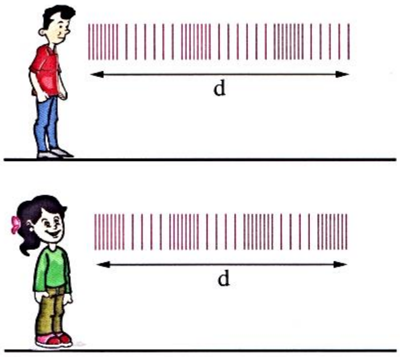
(a) The amplitude ? (b) The wavelength ? (c) The frequency ?

(d) The periodic time ? (e) The wave speed ?

6 The opposite figure shows the sounds which are produced from a man and a girl :

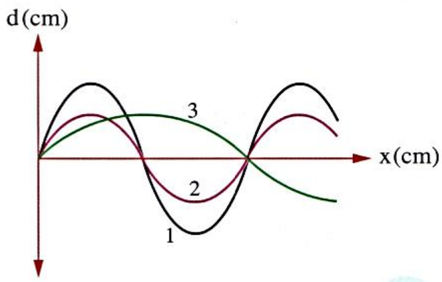
(a) **Which** of the two voices is travelling faster? **And why?**

(b) **Which** of the voices has higher frequency? **And why?**

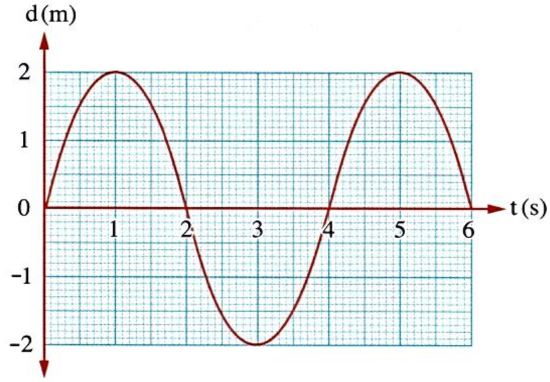


7 The opposite graph represents three waves (1, 2 and 3) where each one of them propagates separately in a tight string which is pulled by a fixed tension force, rank these waves in descending order according to :

(a) Wavelength. (b) Frequency.



8 The opposite graph shows the relation between the vertical displacement and the time of a wave motion which is formed in a rope when its terminal is moved up and down.



(a) **What** is the type of the formed wave in the rope?

(b) **Calculate** the frequency of the wave.

(c) **Draw** with the same scale the relation between the displacement and the time for a wave that has double the frequency and half the amplitude of this wave.

Third Problems

1 A wave was generated in a string, where its frequency was 100 Hz and its wavelength was 0.5 m. **Calculate :**

(a) The wave velocity through the string.

(b) The wavelength if the frequency increased to 300 Hz. (50 m/s, 0.17 m)

2 Transverse waves propagate through a thin thread at velocity 300 m/s. If the distance between two successive crests is 3 m, **calculate** the frequency of the wave. (100 Hz)

3 If 15 waves passed by the edge of a rock extended in the sea in 1 minute and it is observed that every 10 waves occupy 9 m, **find :**

(a) The periodic time. (b) The frequency.

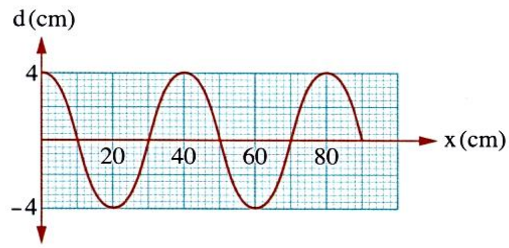
(c) The wavelength. (d) The wave speed. (4 s, 0.25 Hz, 0.9 m, 0.225 m/s)

4 **From the opposite figure, calculate :**

(a) The amplitude of this wave.

(b) The wavelength.

(c) The wave velocity if the frequency is 8 Hz.



(4 cm, 40 cm, 3.2 m/s)

5 **In the opposite figure, find :**

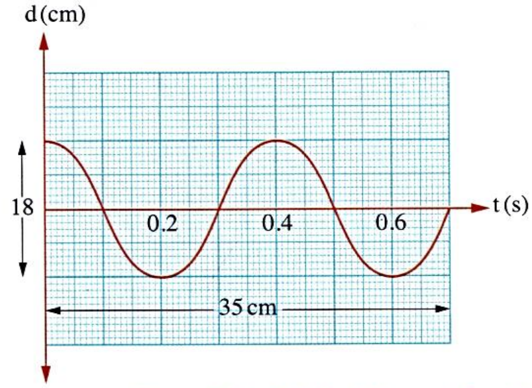
(a) The amplitude.

(b) The periodic time.

(c) The frequency.

(d) The wavelength.

(e) The wave velocity (in two different ways).



(9 cm, 0.4 s, 2.5 Hz, 20 cm, 0.5 m/s)

6 The following table shows the relation between the displacement (d) and the time (t) for a wave that propagates in a medium :

d (m)	0	3	0	– 3	0	3
$t \times 10^{-3}$ (s)	0	0.1	0.2	0.3	0.4	0.5

(a) **Draw** the graph between (d) on the vertical axis and (t) on the horizontal axis.

(b) **From the graph find :**

1- The amplitude of the wave.

2- The periodic time.

3- The frequency.

(3 m , 0.4×10^{-3} s , 2500 Hz)

7 The following table shows the relation between the wavelength (λ) and the frequency (υ) for a wave that propagates in a medium :

λ (m)	2	2.5	4	5	10
υ (Hz)	250	200	a	100	50

(a) **Draw** the graph between (υ) on the vertical axis and $\left(\frac{1}{\lambda}\right)$ on the horizontal axis.

(b) **From the graph find :**

1- The value of a.

2- The wave speed through the medium.

(125 Hz, 500 m/s)

8 The human ear can hear frequencies between 20 Hz and 2×10^4 Hz. **Calculate** the shortest and the longest wavelength that can be heard by the human ear.
(knowing that the speed of sound in air is 340 m/s)

(0.017 m, 17 m)

9. If the number of waves which pass by a certain point is 50 waves every 5 s and the distance between the first and the fourth crest is 120 cm, **calculate** the speed of wave propagation.

(4 m/s)

10. If the speed of water waves that pass by a certain point is 1.5 m/s and there are 30 waves pass by this point in 1 s, **calculate** the number of waves in a distance of 60 m. (1200 waves)

11. If the distance between the second crest and the seventh one of a transverse wave is 20 m and the time between the pass of the first crest and the fifth one by a certain point in the path of the wave motion is 0.1 s, **calculate :**

(a) The wavelength of the wave motion.

(b) The frequency of the source of the disturbance.

(c) The wave speed. (4 m, 40 Hz, 160 m/s)

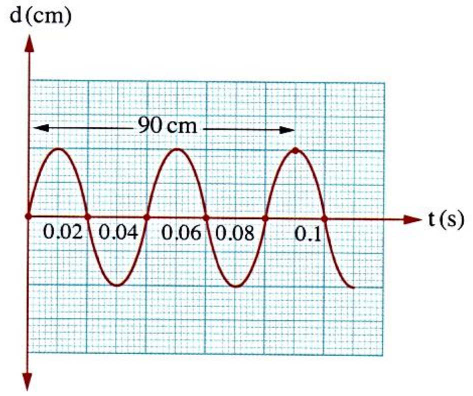
12. A stone was thrown in a lake, so 50 waves were formed after 5 seconds from the collision of the stone with the water, if the radius of the outer circle is 2 m. **Find :**

(a) The wavelength.
(b) The frequency.
(c) The wave speed.
(d) The periodic time. (0.04 m, 10 Hz, 0.4 m/s, 0.1 s)

13. A train, standing in a station, blows a whistle of frequency 300 Hz. If there is a man standing at distance 0.99 km from the train who has heard the sound after 3 s from its production. **Find** the wavelength of the sound in meters. (1.1 m)

14. A tuning fork of frequency 200 Hz was knocked and put at one of the openings of a tube which is opened from both sides and has a length of 8 m, so the beginning of the first wave reached the end of the tube when the sixth wave was about to enter the tube. **Calculate** the speed of sound in air. (320 m/s)

15. **The opposite figure** illustrates the relation between displacement in centimeters and time in seconds for a wave motion.



Calculate :

(a) The wavelength.

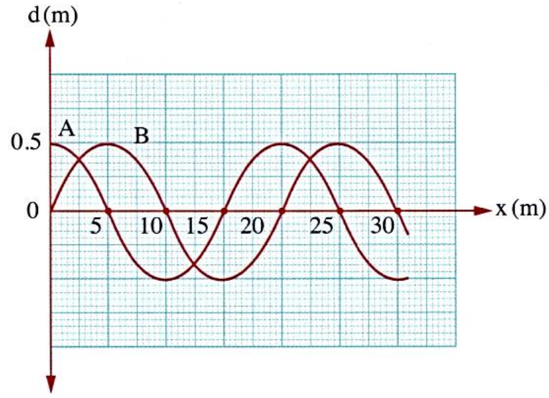
(b) The wave speed. (0.4 m, 10 m/s)

16 Two waves of frequencies 128 Hz and 320 Hz propagate in air at speed 320 m/s. **Calculate** the difference in wavelength between them. (1.5 m)

17 A wireless transmission station sends waves to a satellite at speed 3×10^8 m/s and after 0.03 s the station received the reflected waves by the satellite. **Calculate** the distance between the Earth and the satellite. (4.5×10^3 km)

18 An earthquake monitoring station has detected two types of earthquake waves of different speeds 6000 m/s and 5000 m/s where the time interval between them was 1 minute. If the two types of waves are produced from the same source, **find** the distance between the source and the station. (18×10^5 m)

19 **In the opposite figure,** curve A represents the relation between the displacement (d) on the vertical axis and the distance (x) covered by a wave on the horizontal axis at a certain instant, while curve B represents the same relation for the same wave with a time difference 2 seconds ($\frac{1}{4}$ of the periodic time), **calculate :**

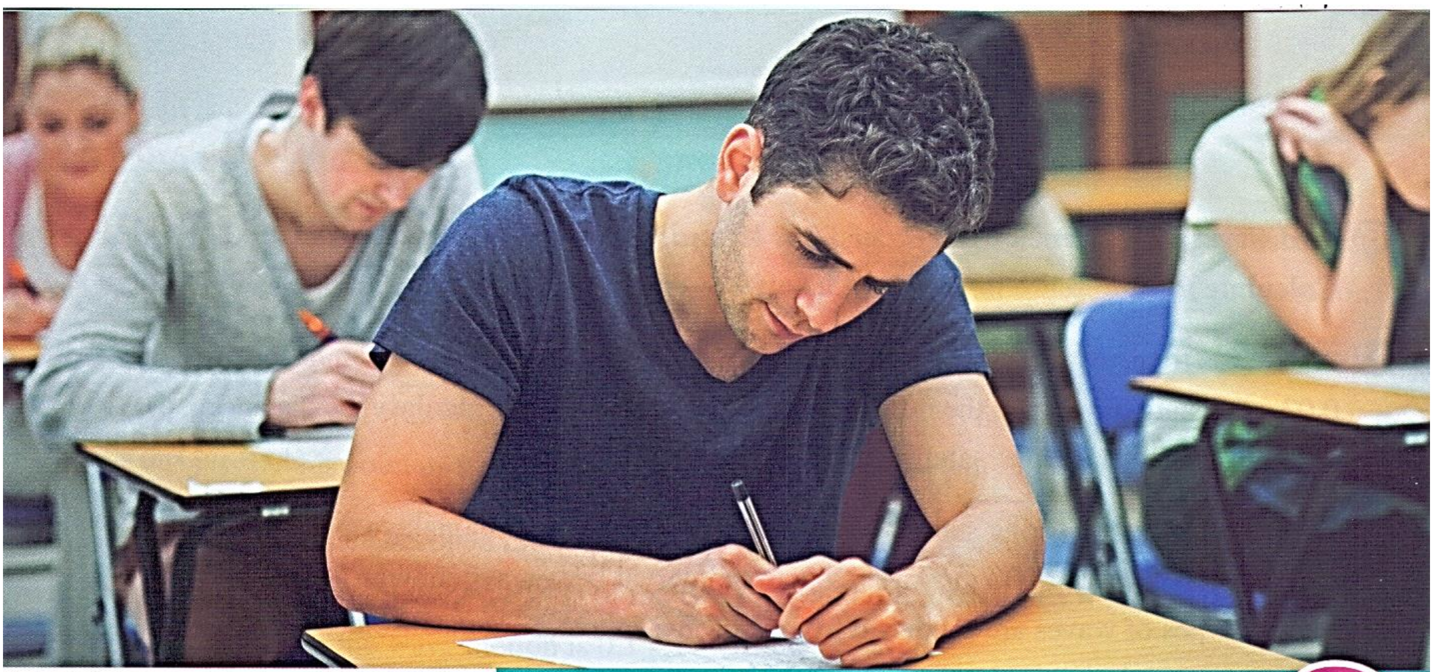


(a) The wavelength.
(b) The amplitude.
(c) The frequency.
(d) The speed of wave propagation. (20 m , 0.5 m , 0.125 Hz , 2.5 m/s)

20 An oscillating body produces a complete oscillation of sound every 0.02 s that reaches a person at distance 170 m from the body after 0.5 s. **Calculate** the distance between the centers of the first compression and the second rarefaction. (10.2 m)

21 Two ships A and B are stationary. Ship A sends two sound signals, one through the air and the other through the water, if the signal that is transmitted in air reaches ship B 6 s after the signal that is transmitted in water, **find** the distance between the two ships. (knowing that : The speed of sound in air is 340 m/s and in water is 1480 m/s) (2.65 km)

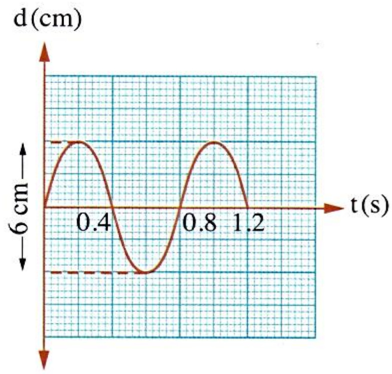
22 Two tones have frequencies 680 Hz and 425 Hz in air. If the wavelength of one of them exceeds the wavelength of the other wave by 30 cm, **calculate** the speed of sound in air. (340 m/s)



TEST ON Chapter 1 Wave Motion

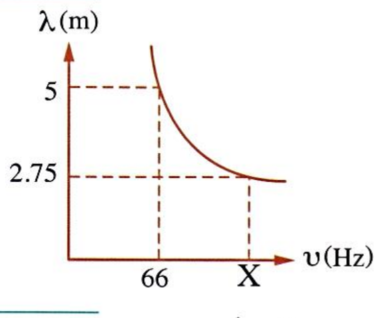
First Choose the correct answer

1 The opposite figure represents (displacement - time) graph for a particle in a medium that transmits a transverse wave, so ....



	Amplitude (A) cm	Frequency (υ) Hz
a	6	2.5
b	6	0.4
c	3	1.25
d	3	0.8

2 The opposite graph shows the relation between the wavelength and the frequency of the sound wave for a number of tuning forks that vibrate in air, so the value of X is ....



ⓐ 75 Hz ⓑ 120 Hz
ⓒ 122 Hz ⓓ 150 Hz

3 The ratio between periodic time and frequency of an oscillating object equals $\frac{1}{289}$ s^2, so the number of oscillations that are produced in 20 s equals .... oscillations.

ⓐ 170 ⓑ 289 ⓒ 340 ⓓ 510

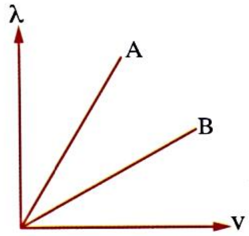
4. A sound wave travelled from air to water. If the wavelengths of that wave in air and water are 0.5 m and 2.1 m respectively and the speed of sound in air is 330 m/s, the speed of sound in water is ....

(a) 1420 m/s (b) 1386 m/s (c) 1320 m/s (d) 693 m/s

5. If the time taken by an oscillating object to make one oscillation is 20 ms, the number of complete oscillations which the object makes during 5 s equals .... oscillations.

(a) 100 (b) 200 (c) 250 (d) 400

6. The opposite graph shows the relation between the wavelength and the speed of two different waves (A and B) which propagate in different media, so ....



(a) $T_A > T_B$ (b) $T_A < T_B$

(c) $\upsilon_A > \upsilon_B$ (d) $\upsilon_A = \upsilon_B$

7. When moving the terminal of a long spring in such a way to make a longitudinal wave of wavelength 25 cm and periodic time 0.25 s, then moving the terminal to make a transverse wave of periodic time 0.1 s and a speed that equals the same speed as the longitudinal wave, so the wavelength of the transverse wave is ....

(a) 17.5 cm (b) 15 cm (c) 12.5 cm (d) 10 cm

8. A transverse wave travels at a speed of 340 m/s and has a frequency of 170 Hz. If the vertical distance between a crest and a trough in it equals the horizontal distance between a crest and its successive trough, so the amplitude of the wave equals ....

(a) 0.25 m (b) 0.5 m (c) 0.75 m (d) 1 m

9. Two sound waves of frequencies 300 Hz, 600 Hz travels in air, so the ratio between their speeds is ....

(a) $\frac{1}{2}$ (b) 1 (c) 2 (d) $\frac{1}{4}$

10. A drop of water fell on the surface of a still water, so 120 wave ripples are produced during half minute. If the radius of the external circle is 3 m, the speed of propagation of the wave equals ....

(a) 0.01 m/s (b) 0.1 m/s (c) 0.5 m/s (d) 1 m/s

Second Answer the following questions

11 The opposite figure shows a pendulum that is displaced away from its equilibrium position then left to move, **explain** the energy transformations after leaving the pendulum immediately.

....

....

....

12 **How does** the increase of wavelength by 50 % affect the frequency of a wave that travels in a rope ?

....

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13 If you want to increase the wavelength of a travelling wave in a rope, **does** the rope have to vibrate with a larger or a smaller frequency than the first case ?

....

....

14 If a wave travelled between two media so that its speed increased by 20 %, **what** is the percentage of change in its wavelength ?

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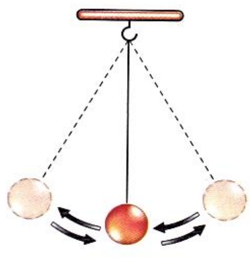
15 In the opposite figure, if the pendulum was making 30 complete oscillations per one minute, **calculate** the frequency and the periodic time.



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16 Two sound waves of frequencies 255 Hz and 510 Hz are propagating in air. If the wavelength of one of them is larger than the other by $\frac{2}{3}$ m, **calculate** the speed of sound in air.

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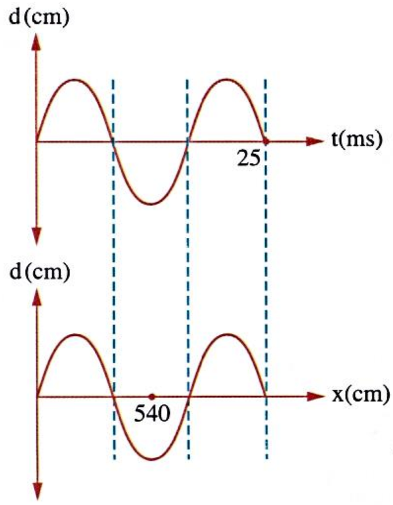
17 The two opposite graphs show the relation between the displacement of the particles of the medium and both time and distance of propagation for the same wave motion. **Calculate** the speed of the wave.



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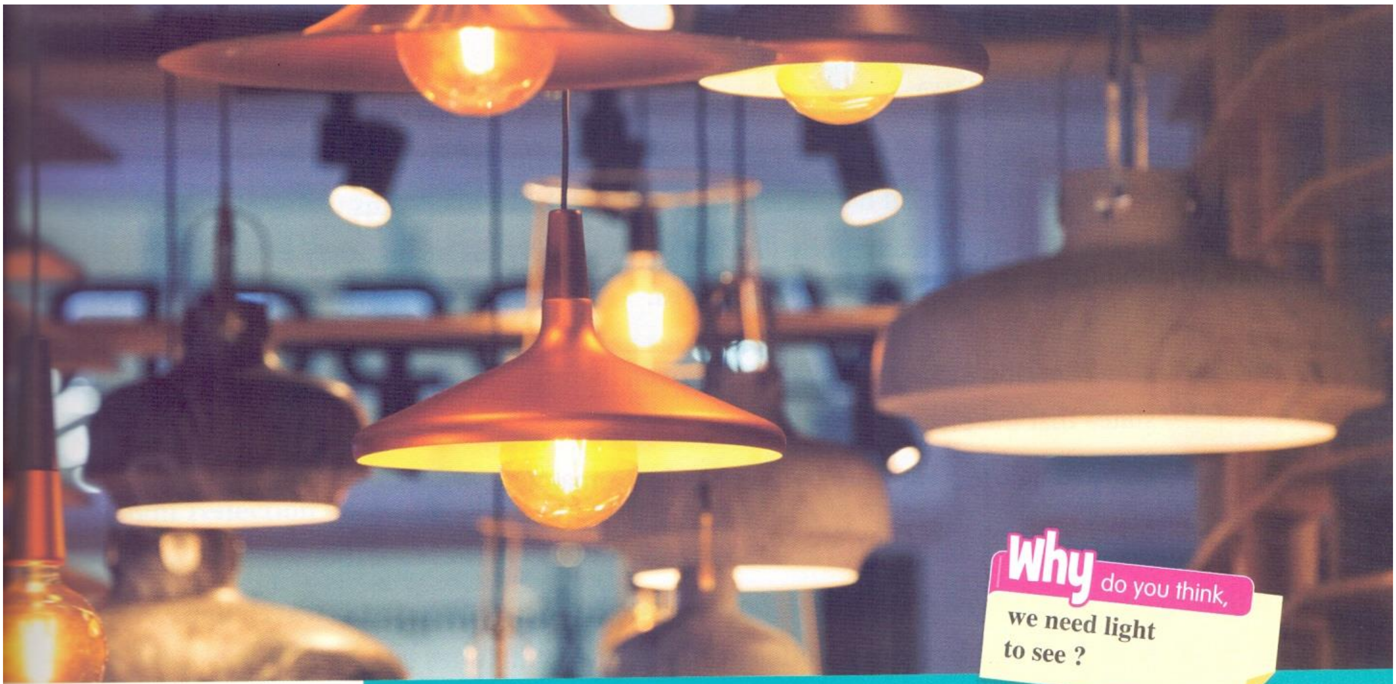


Chapter 2

Lesson One

Properties of Light

(Propagation, Reflection and Refraction)

- Sun is the main energy source for life on Earth and light is the essential way of transferring this energy to Earth, where :
  - Energy is produced in Sun and transfers through space in the form of electromagnetic waves which are mostly light waves.
  - This energy is stored by plants through a process which is called photosynthesis.
  - Energy transfers to animals and humans by eating these plants as food.
  - Also fossil fuels had been formed from plants and animals that had been buried for millions of years in the Earth's crust.

Wave nature of light

EKB

- Scientists thought that all waves need a medium through which they can transfer. So, both sound and light need a medium to transfer, therefore they assumed that space is filled with a medium that transfers light waves called ether.
- In 1873, the British scientist James Clerk Maxwell developed his equations according to the previous work of Michael Faraday which proved the connection between the electric field and the magnetic field where the vibrations or the motion of charges generate transverse electromagnetic waves and when Maxwell found that the calculations of the speed of electromagnetic waves are similar to that of the speed of light, he predicted that light is a transverse electromagnetic wave.
- As the propagation of electric fields or magnetic fields doesn't require a physical medium, the electromagnetic waves also don't require the existence of a physical medium through which they can spread which led scientists to abandon the idea of ether.

In old times

- In the study of light nature, physicists divided into two teams :

- Isaac Newton's team : they thought that light is made of a very small particles.
- Hygens' team : they thought that light is a wave.

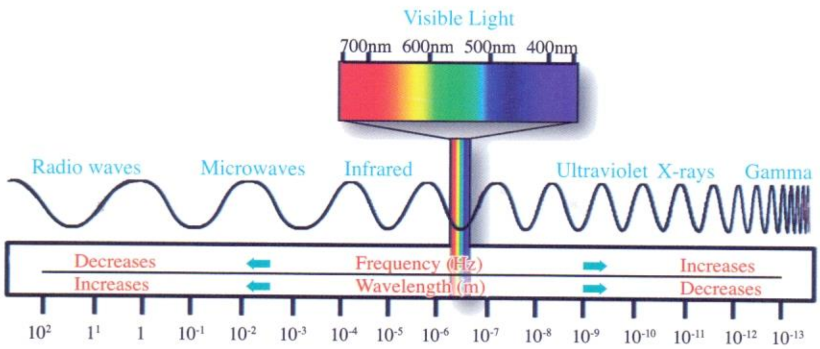
Recently

However, the modern Physics has proven the principle of dual nature of light, which states that the electromagnetic waves have :

1. Wave nature : They are transverse electromagnetic waves.
2. Particle nature : They are consisting of particles called photons.

Electromagnetic waves have an extensive range of frequencies and wavelengths, this range is called the electromagnetic spectrum and it includes :

- Radio waves.
- Microwaves.
- Infrared waves.
- Visible light waves.
- Ultraviolet waves.
- X-rays.
- Gamma rays.



From the figure it is clear that visible light is a limited part of the electromagnetic spectrum and it has the following properties :

Properties of light waves

1. Propagation
2. Reflection
3. Refraction
4. Interference
5. Diffraction

First Light propagation

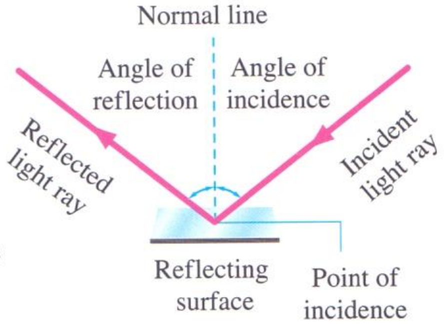
- Light propagates in straight lines in all directions as long as it travels in the same homogeneous medium which means no other medium or barrier comes into its way.

Second Light reflection

⊙ Occurrence :

When light falls in a medium on a reflecting surface, it bounces back in the same medium and this phenomenon is known as **light reflection**.

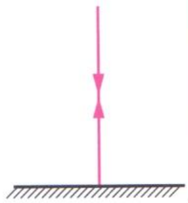
⊙ Light reflection obeys two laws, which are :



- **The first law :**
  Angle of incidence = Angle of reflection
- **The second law :** The incident light ray, the reflected light ray and the normal line at the point of incidence all lie in the same plane which is perpendicular to the reflecting surface.

Notes :

1. The speed of light in empty space is a universal constant that equals 3×10^8 m/s and it is greater than its speed in any other medium.



2. The light ray which falls perpendicular on a reflecting surface reflects on itself because the angle of incidence = The angle of reflection = zero
3. It is easier to see your reflection on the glass window of a lighted room at night when the outside is dark than seeing your reflection in the daytime :

because

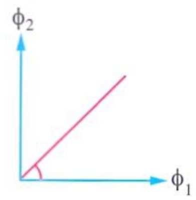
⊙ When outside of the room is so dark :

The intensity of light passing from outside into the room is very small. So, the person can see his image as a result of the small amount of light that is reflected on the glass inside the room.

⊙ When outside of the room is lighted :

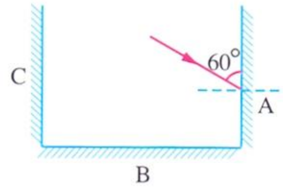
The intensity of light passing from outside is larger than the reflected light intensity inside the room. So, it is difficult for the person to see his image by reflection.

4. When drawing the relation between the angle of incidence (ϕ_1) and the angle of reflection (ϕ_2) with the same scale we get a line of slope 1 as in the opposite graph.



Example

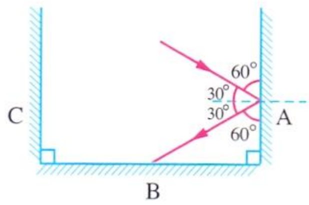
Three mirrors; A, B and C, are perpendicular to each other as shown in the figure. If a light ray falls on mirror A, where the confined angle between the incident light ray and the surface of the mirror is 60°, trace the path of the light until its reflection at mirror C.



Solution

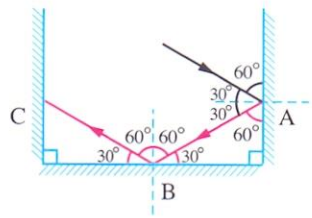
Clue

When the ray falls on mirror A such that the angle between the ray and the surface of the mirror is 60°, it means that the angle of incidence is 30° and as the angle of incidence = The angle of reflection, so the angle of reflection on mirror A is 30°, then the ray falls on mirror B.



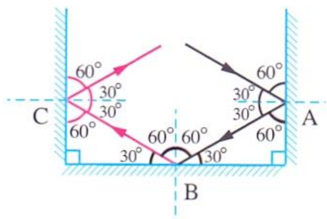
Clue

When the ray falls on mirror B, the angle between the falling ray and the surface of the mirror equals 30°, hence the angle of incidence equals 60°, so the ray reflects from mirror B with an angle of 60° to fall on mirror C.



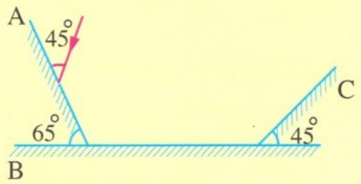
Clue

When the ray falls on mirror C the angle between the falling ray and the surface of the mirror equals 60°, therefore the angle of incidence equals 30°, then the ray reflects at mirror C with an angle of 30°.



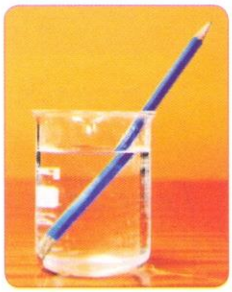
Test yourself

The opposite figure shows three mirrors A , B and C. If a light ray fell on mirror A as shown in the figure, trace the path of the ray until it reflects from mirror C.



Third Light refraction

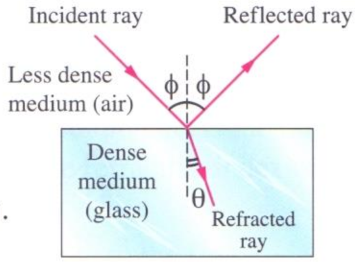
- If you put a pen in a glass of water and look at it from its side, you will see the pen as if it is bent and this happens due to the refraction of light.



Occurrence :

When a light ray falls on a separating surface (boundary surface) between two transparent media where the speed of light in the first one is v_1 and in the second is v_2;

- Very small part of light is absorbed in the second medium.
- Part of the light ray is reflected in the first medium.
- The remaining part passes to the second medium, changing its direction and this phenomenon is known as **light refraction**.



Causes :

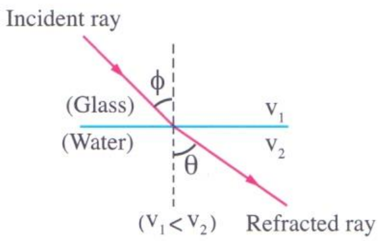
- The refraction of light occurs due to the different speeds of light in the two media as a result of the different optical densities of the two media.

Optical density of a medium : The ability of the medium to bend light rays when they enter into it.

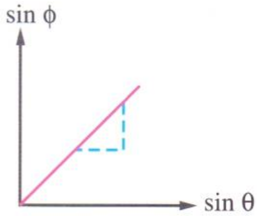
Light refraction obeys two laws, which are :

- **First law :** The ratio between the sine of the angle of incidence ($\sin \phi$) in the first medium to the sine of the angle of refraction ($\sin \theta$) in the second medium equals the ratio of the speed of light (v_1) in the first medium to the speed of light (v_2) in the second medium which is a constant ratio for the two media and it is called **relative refractive index** ($_1n_2$).

$$_1n_2 = \frac{\sin \phi}{\sin \theta} = \frac{v_1}{v_2} = \frac{\lambda_1}{\lambda_2}$$



- **Second law :** The incident light ray, the refracted light ray and the normal line at the point of incidence all lie in the same plane which is perpendicular to the separating surface between the two media.



From the first law : Its obvious that $\sin\phi \propto \sin\theta$
So when plotting the relation between $\sin\phi$ and $\sin\theta$, we get a straight line as in the opposite figure whose slope represents the relative refractive index between the two media.

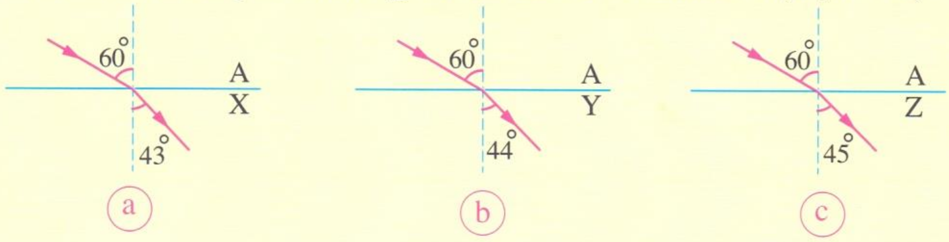
$$\text{Slope} = \frac{\Delta \sin\phi}{\Delta \sin\theta} = {}_1n_2$$

The factors affecting the relative refractive index between two media :

1. The wavelength of the incident light ray.
2. The types of the two media (the speed of light in that medium).

2 Test yourself

Choose : The three following figures are representing three light rays of the same wavelength falling from medium A to three different media X, Y and Z each one at a time, which of them has the largest wavelength in the medium of refraction (X , Y or Z)? ....

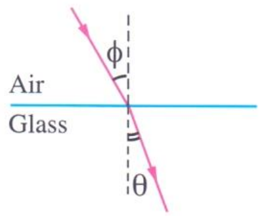


The absolute refractive index of a medium

- If a light ray passes from space or air into another transparent medium :
The ratio of the sine of the angle of incidence in the space ($\sin\phi$) to the sine of the angle of refraction in the medium ($\sin\theta$) equals the ratio of the speed of light in space (c) to the speed of light (v) in the medium, which is a constant ratio for this medium and it is called the **absolute refractive index of the medium (n)**.

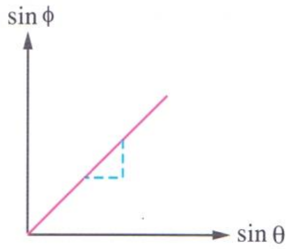
i.e.

$$n = \frac{\sin\phi}{\sin\theta} = \frac{c}{v} = \frac{\lambda_{(air)}}{\lambda_{(medium)}}$$



- The value of the absolute refractive index of any medium is always greater than one because the speed of light in space is greater than its speed in any other medium.

- The absolute refractive index has no measuring units because it is a ratio between two similar physical quantities.
- The absolute refractive index of a medium is inversely proportional to the speed of light in this medium ($n \propto \frac{1}{v}$).
- When plotting the relation between ($\sin \phi$) in air and ($\sin \theta$) in any other medium, we get a straight line as in the opposite figure.
- The slope of the line represents the absolute refractive index (n) for this medium.



$$\text{Slope} = \frac{\Delta \sin \phi}{\Delta \sin \theta} = n$$

The factors affecting the absolute refractive index of a medium :

1. The wavelength of the incident light ray (the refractive index of a medium decreases as the wavelength increases).
2. The type of the medium (the speed of light in this medium).

The relation between the relative refractive index and the absolute refractive index :

$$\because n = \frac{c}{v} \quad , \quad v = \frac{c}{n} \qquad \therefore \frac{v_1}{v_2} = \frac{n_2}{n_1}$$

$$\because {}_1n_2 = \frac{v_1}{v_2} \qquad \therefore \boxed{{}_1n_2 = \frac{n_2}{n_1}}$$

i.e. The relative refractive index from the first medium to the second medium equals the ratio of the absolute refractive index of the second medium to the absolute refractive index of the first medium.

And, accordingly the relative refractive index from the second medium to the first medium can be obtained from the relation : $\boxed{{}_2n_1 = \frac{n_1}{n_2} = \frac{1}{{}_1n_2}}$

Snell's law

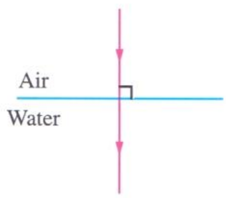
- From the first law of refraction :

$$\because {}_1n_2 = \frac{\sin \phi}{\sin \theta} \quad , \quad \because {}_1n_2 = \frac{n_2}{n_1}$$

$$\therefore \frac{\sin \phi}{\sin \theta} = \frac{n_2}{n_1} \qquad \therefore \boxed{n_1 \sin \phi = n_2 \sin \theta}$$

Note :

- The light ray that falls perpendicularly on the boundary between two media, doesn't suffer any refraction because according to Snell's law ($n_1 \sin \phi = n_2 \sin \theta$), when the light ray falls normally on the separating surface between the two media ($\phi = 0°$), then ($n_2 \sin \theta = 0$) and the angle of refraction ($\theta = 0°$).



Example 1

If the absolute refractive index of water is $\frac{4}{3}$ and the absolute refractive index of glass is $\frac{3}{2}$, calculate :

(a) The relative refractive index from water to glass.

(b) The relative refractive index from glass to water.

Solution

$n_g = \frac{3}{2}$ $\quad$ $n_w = \frac{4}{3}$

(a) $_w n_g = \frac{n_g}{n_w} = \frac{\frac{3}{2}}{\frac{4}{3}} = \frac{9}{8} = 1.125$

(b) $_g n_w = \frac{n_w}{n_g} = \frac{\frac{4}{3}}{\frac{3}{2}} = \frac{8}{9} = 0.889$

Example 2

A light ray of wavelength 589 nm falls in air on the surface of a glass plate of refractive index 1.52 at an angle of incidence 30°, calculate :

(a) The angle of refraction of the ray.

(b) The speed of light inside the glass.

(c) The wavelength of light inside the glass.

(the speed of light in air = 3×10^8 m/s)

Solution

(a) $\lambda_a = 589$ nm $\quad$ $n = 1.52$ $\quad$ $\phi = 30°$ $\quad$ $c = 3 \times 10^8$ m/s

$$n = \frac{\sin \phi}{\sin \theta}$$

$$\sin \theta = \frac{\sin \phi}{n} = \frac{\sin 30}{1.52} \quad , \quad \theta = 19.2°$$

(b) $n = \frac{c}{v}$

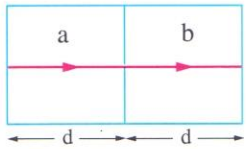
$$v = \frac{c}{n} = \frac{3 \times 10^8}{1.52} = 1.97 \times 10^8 \text{ m/s}$$

(c) $\because \upsilon_a = \upsilon_g \qquad \therefore \frac{c}{\lambda_a} = \frac{v}{\lambda_g} \qquad \therefore n = \frac{\lambda_a}{\lambda_g}$

$$\lambda_g = \frac{\lambda_a}{n} = \frac{589}{1.52} = 387.5 \text{ nm}$$

Example 3

The opposite figure shows a light ray that travels from medium a to another medium b, if the number of complete waves in medium a equals 10^5 waves and the number of complete waves in medium b equals 1.5×10^5 waves, find the relative refractive index ${}_an_b$.



Solution

$N_a = 10^5$ $N_b = 1.5 \times 10^5$

$$\lambda = \frac{X}{N}$$

$$\lambda_a = \frac{d}{10^5} \quad , \quad \lambda_b = \frac{d}{1.5 \times 10^5}$$

$${}_an_b = \frac{v_a}{v_b} = \frac{\lambda_a}{\lambda_b} = \frac{d \times 1.5 \times 10^5}{10^5 \times d} = 1.5$$

3 Test yourself

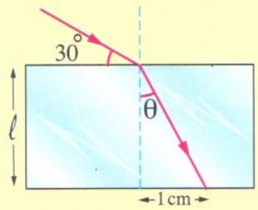
(1) If a light ray falls on a glass surface at an angle of incidence 60°, a small part of the light reflects and the other part refracts, **calculate** the angle between the reflected and the refracted light rays. (the refractive index of glass = 1.5)

....

....

....

(2) The opposite figure shows a light ray falling on a glass slab of thickness ℓ , if the refractive index of the slab is $\sqrt{3}$, **calculate** its thickness ℓ.



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Add to your information

Explanation of light refraction

- When a light ray falls from an optically rarer (less dense) medium to an optically denser one (from air to glass), the light ray refracts approaching the normal line.

  This can be resembled by a car when one of its wheels enters through a muddy soil, which makes it slow down, while the other wheel is moving on the paved road faster than the first one. Therefore, the car changes its direction. Fig. (A)

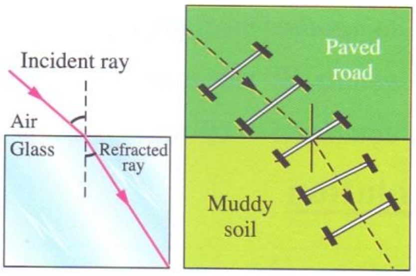


Fig. (A)

- The opposite occurs, as in refraction from an optically denser medium to an optically rarer one. The refracted ray refracts away from the normal. Fig. (B)

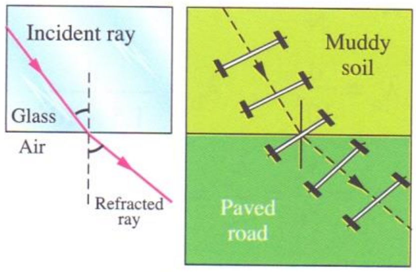


Fig. (B)

QUESTIONS ON

Chapter 2

LESSON ONE

Properties of Light

(Propagation, Reflection and Refraction)

Interactive test

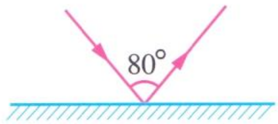
First Multiple choice questions

1 If the opposite table shows some selected wavelengths from the electromagnetic spectrum in air, so ....

	Wavelength
Invisible light	M
Gamma rays	Y
X-rays	Z

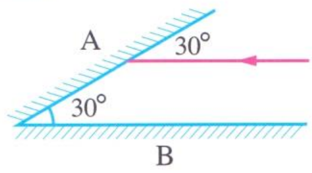
(a) M < Z < Y
(b) Y < Z < M
(c) Y < Z = M
(d) Y = Z > M

2 The opposite figure shows a light ray which is falling on the surface of a plane mirror and bouncing back, hence the angle of reflection of the ray from the mirror equals ....



(a) 40° (b) 50° (c) 80° (d) 100°

3 If a light ray fell on mirror A such that it was parallel to mirror B as shown in the opposite figure :



(i) The light ray would be reflected from mirror A and fell on mirror B by an angle of incidence that equals ....

(a) 90° (b) 60° (c) 30° (d) 0°

(ii) The reflected light ray from mirror B would fall again on mirror A with an angle of incidence that equals ....

(a) 90° (b) 45° (c) 30° (d) 0°

4 When a light ray passes from an optically rarer medium to another optically denser medium with an angle of incidence = zero, which of the following light properties does not change ? ....

(a) Speed
(b) Wavelength
(c) Direction
(d) No correct answer

5 When a light ray falls from air on water surface at an angle of 60°, the angle of refraction will be ....

(a) greater than 60° (b) less than 60° (c) equal to 60° (d) equal to 0°

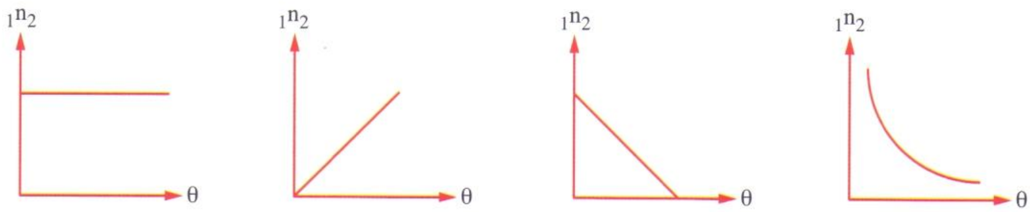
6. When a light ray falls on the interface between two media at an angle of incidence ϕ and refracts at an angle of refraction θ, the ratio $\frac{\sin \phi}{\sin \theta}$ is ....

(a) constant for the two media (b) variable according to the value of ϕ
(c) constant and greater than one (d) constant and less than one

7. When the angle of incidence on the boundary surface between two media doubles, the relative refractive index of them ....

(a) decreases to half (b) doubles (c) remains constant (d) triples

8. Which of the following graphs represents the relation between the relative refractive index between two media and the angle of refraction in one of them ? ....

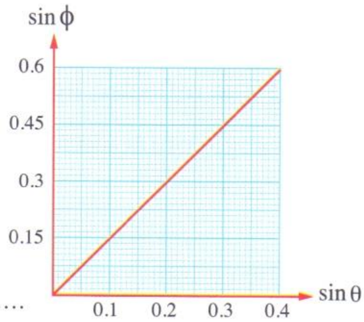


(a) (b) (c) (d)

9. A light ray falls on the boundary surface between two media, if the angle of incidence is 60° and the angle of refraction is 30°, the relative refractive index from the first medium to the second medium equals ....

(a) 2 (b) $\sqrt{3}$ (c) $\sqrt{2}$ (d) $\frac{1}{2}$

10. The opposite graph represents the relation between the sine of the angle of incidence in a transparent medium to the sine of the angle of refraction in another medium when a light ray travels between them. If the speed of light in the first medium is 2×10^8 m/s , then :



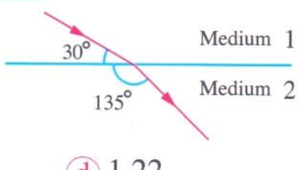
(i) The relative refractive index between the two media = ...

(a) 1.5 (b) 0.75 (c) 1.93 (d) 2

(ii) The speed of light in the second medium = ... m/s

(a) 3.8×10^8 (b) 3.3×10^8 (c) 2.7×10^8 (d) 1.33×10^8

11. The opposite figure shows a light ray falling from medium 1 on the boundary surface with medium 2, so the relative refractive index from medium 1 to medium 2 equals ....



(a) 1.52 (b) 1.48 (c) 1.34 (d) 1.22

12. A red light ray falls from air on the surface of glass. If the wavelength of red light in space is 7000 Å and the refractive index of glass is 1.5, the wavelength of red light in glass is ....
(a) 10500 Å (b) 8564 Å (c) 5543 Å (d) 4667 Å

13. If a light ray falls on a glass surface at an angle of incidence 60° and the absolute refractive index of glass is $\sqrt{3}$, the angle of refraction of the light ray equals ....
(a) 30° (b) 45° (c) 60° (d) 90°

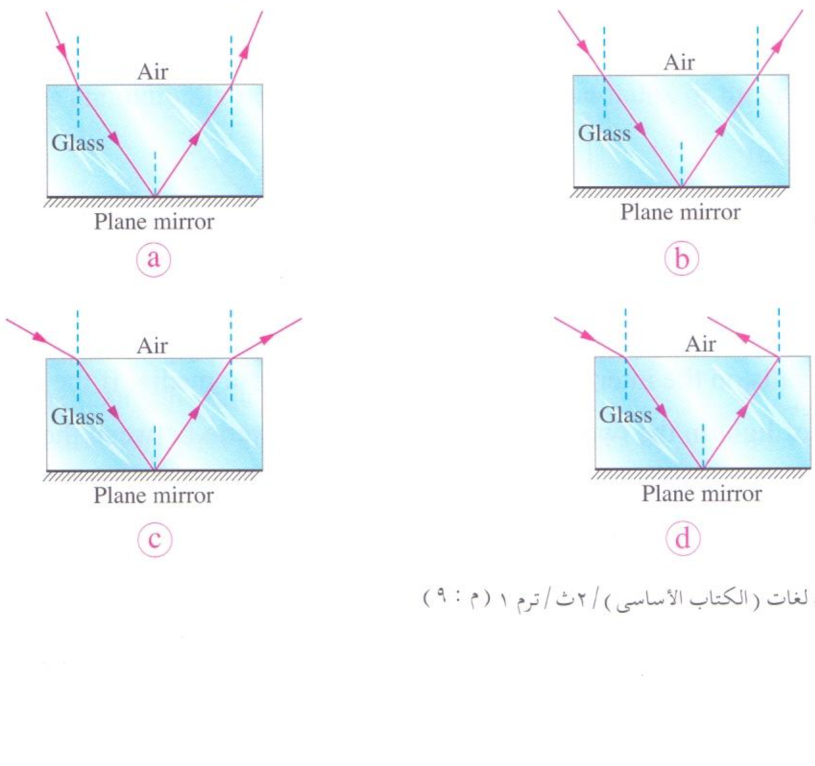
14. If the absolute refractive index of gasoline $n_1 = 1.5$ and the absolute refractive index of rock glass $n_2 = 1.66$, so the relative refractive index from gasoline to rock glass $_1n_2$ equals ....
(a) 0.91 (b) 1.1 (c) 1.25 (d) 1.5

15. If the ratio between the refractive index of the first medium and the refractive index of the second medium is $\frac{2}{1}$, the ratio between the speed of light in the first medium and the speed of light in the second medium is ....
(a) $\frac{2}{1}$ (b) $\frac{1}{2}$ (c) $\frac{4}{1}$ (d) $\frac{1}{4}$

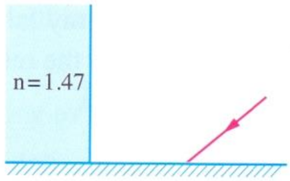
16. When a light ray falls at an angle from a medium of refractive index 1.2 on a surface of another medium of refractive index 1.5, ...
(a) its speed increases and it refracts toward the normal line
(b) its speed decreases and it refracts toward the normal line
(c) its speed decreases and it refracts away from the normal line
(d) its speed increases and it refracts away from the normal line

17. A light ray falls from air on the surface of a glass slab at an angle of 52°. If the ray is deviated by an angle 19°, the refractive index of glass is ....
(a) 0.83 (b) 1.33 (c) 1.45 (d) 1.65

18. A monochromatic light ray falls from air into a cuboid of glass which is placed above a plane mirror, so the correct path of the ray is represented in figure ....



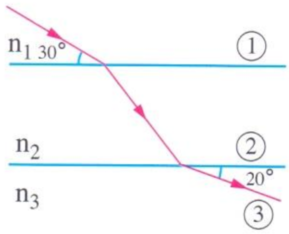
19 The opposite figure shows a glass plate which is put vertically on the surface of a plane mirror, if a light ray falls at an angle 50° on the surface of the mirror, its angle of refraction in the glass plate will be ....



(a) 51.6° (b) 47.2° (c) 35.8° (d) 25.9°

---

20 The opposite figure shows a light ray travelling through three different media, so the relation between the refractive indices of these media is demonstrated by ....



(a) $n_3 > n_1 > n_2$ (b) $n_1 > n_2 > n_3$

(c) $n_2 > n_1 > n_3$ (d) $n_2 > n_3 > n_1$

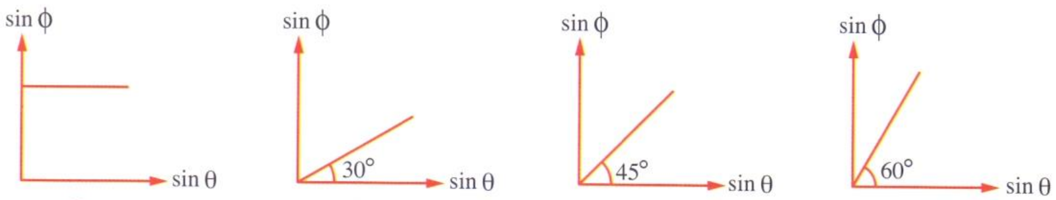
---

21 A light ray fell on a surface of a glass cuboid and it came out from the opposite surface with an angle of 50°. If the refractive index of the glass is 1.53 so .... , ...

	The angle of incidence	The angle of refraction inside the cuboid
(a)	40°	30°
(b)	40°	45°
(c)	50°	30°
(d)	50°	45°

---

22 If a light ray travelled from a medium of refractive index n_1 to another medium of refractive index n_2 where $n_2 > n_1$, the nearest graphical representation of the relation between sin ϕ and sin θ, when they are drawn with the same scale, could be ....



(a) (b) (c) (d)

---

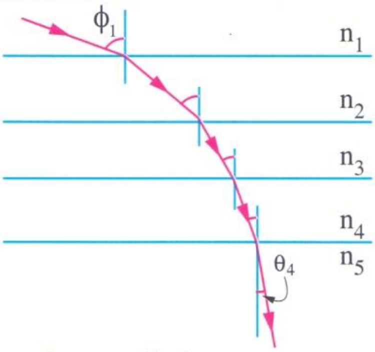
23 A light ray falls on the interface between two transparent media. If the ratio between the speeds of light in the two media $\left(\frac{V_1}{V_2}\right) = \frac{2}{3}$, so the ratio between the frequencies of light waves in the two media equals ....

(a) $\frac{1}{3}$ (b) $\frac{2}{3}$ (c) 1 (d) 2

24 If the absolute refractive index of water is 1.33, then the time taken by light to move a distance 20 m in water equals .... (The speed of light in air = 3×10^8 m/s)

(a) 8.87×10^{-8} s (b) 1.13×10^{-7} s (c) 2.25×10^{-8} s (d) 4.52×10^{-9} s

25 The opposite figure shows a light ray falling on successive parallel layers of transparent media of different refractive indices, so :



(i) The ratio $\frac{\sin \phi_1}{\sin \theta_4}$ depends on ....

(a) n_1 , n_5 only (b) n_2 , n_3 , n_4 only

(c) n_1 , n_2 , n_3 , n_4 , n_5 (d) n_1 , n_2 only

(ii) The medium in which the speed of light is greater than the other media is ....

(a) 1 (b) 2 (c) 3 (d) 4

26 Monochromatic light is refracted from air into a glass of refractive index μ . The ratio of the wavelengths of incident and refracted waves is ....

(a) $1 : \mu$ (b) $1 : \mu^2$ (c) $\mu : 1$ (d) $1 : 1$

27 One side of a glass slab is silvered as shown. A ray of light is incident on the other side at angle of incidence $\phi = 45°$. Refractive index of glass is given as 1.5. The deviation of the light ray from its initial path when it comes out of the slab is ....

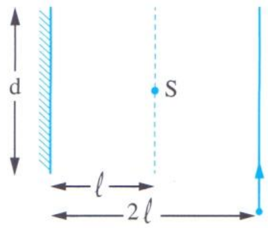
(a) 90° (b) 180°

(c) 120° (d) 45°

28 A light wave is incident at an angle of 60° on a glass plate. If the reflected and the refracted waves are mutually perpendicular, the refractive index of the material is ....

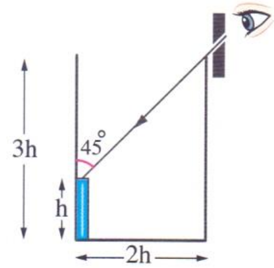
(a) $\frac{\sqrt{3}}{2}$ (b) $\sqrt{3}$ (c) $\frac{3}{2}$ (d) $\frac{1}{\sqrt{3}}$

29 A source of light S is placed at a distance ℓ in front of the center of a mirror of width d that is hung vertically on a wall. A man walks in front of the mirror along a line parallel to the mirror at a distance 2ℓ from it as shown. The maximum distance that the man can walk while seeing the reflected image of the source of light before it disappears at the edges of the mirror is ....



(a) d/2 (b) d (c) 2d (d) 3d

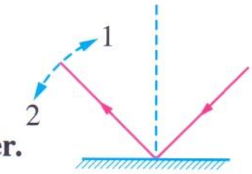
30 An observer can see through a pinhole the top end of a thin rod of height h which is placed in a beaker as shown in the figure. The beaker height is 3 h and its radius is h. When the beaker is filled with a liquid up to a height 2h, he can see the lower end of the rod through the pinhole. Then the refractive index of the liquid is ....



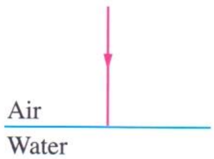
(a) $\frac{5}{2}$ (b) $\sqrt{\frac{5}{2}}$ (c) $\sqrt{\frac{3}{2}}$ (d) $\frac{3}{2}$

Second Essay questions

1 The opposite figure shows the reflection of a light ray. If the angle of incidence increased, **does** the reflected ray deflect? And if it is deflected, in which direction will it be deflected? **Explain your answer.**



2 The opposite figure shows a light ray which is falling perpendicularly from air on the surface of water. **Find the value of the angle of refraction with explaining your answer.**



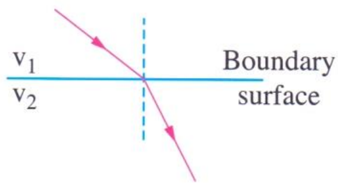
3 A ray travelled from a medium of refractive index n_1 to another medium of refractive index n_2. **Show by drawings the path of the light ray through the two media if :**

(1) $n_2 < n_1$ **(2)** $n_2 > n_1$

4 **Which of the following quantities is smaller, equal or larger than one :**

(1) The ratio between the sine of the angle of incidence of the light ray in glass ($n_g = 1.5$) and the angle of refraction in water ($n_w = 1.33$).

(2) The ratio $\frac{v_1}{v_2}$ in the opposite figure.

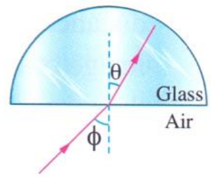


5 **Explain the following statements :**

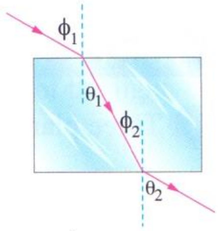
(1) It is easier to see your reflected image on the glass of a window from the inside of a lighted room at night when the outside is dark than seeing your reflection at daytime when the outside is lighted.

(2) The absolute refractive index for any medium is always greater than one however the relative refractive index may be less or greater than one.

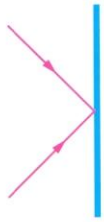
6 The opposite figure shows a red light ray falling on a half disc of glass, **will** the angle of refraction change if a blue light ray is used instead of the red light? **Explain your answer.**



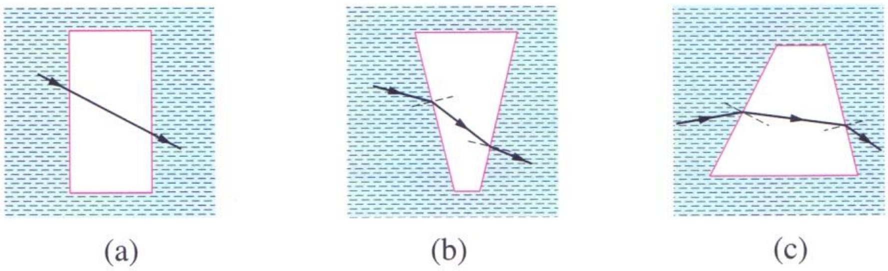
7 The opposite figure shows the path of a light ray falling on a glass cuboid.
Prove that : $\phi_1 = \theta_2$



8 In the opposite figure two light rays intersect at a point on a vertical screen. If a glass plate is put in front of the screen in the path of the two rays, **will** the two rays intersect on the screen? **Explain your answer.**



9 **Study the following figures and answer :**



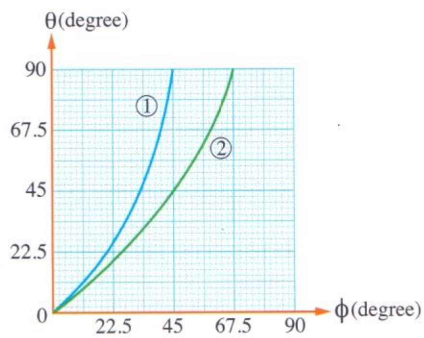
Which of these figures represents :

(1) Falling of a ray from a liquid of refractive index 1.5 to a glass of refractive index 1.5

(2) Falling of a ray from a liquid of refractive index 1.3 to a glass of refractive index 1.5

(3) Falling of a ray from a liquid of refractive index 1.8 to a glass of refractive index 1.5

10 A light ray transfers from a medium of refractive index n_1 to water, then the medium is replaced with another of n_2. If the opposite graph depicts the relations between the angle of incidence (ϕ) in both media (1 and 2) and the angle of refraction (θ) in water :

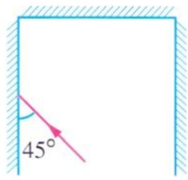


(1) Which of the two media (1 or 2) has the greater refractive index? **And why** ?

(2) Calculate the refractive indices of media 1 and 2 (if you know that : $n_{water} = 1.33$)

Third Problems

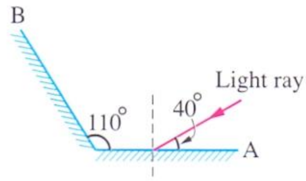
1 Three plane mirrors are formed as three sides of a square as in the opposite figure. **Trace the path of** a light ray that falls on one of them until its reflection from the three mirrors.



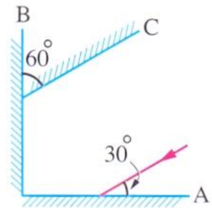
2 **In the opposite figure :**

(a) A light ray falls on a plane mirror (A) and reflects from it towards a plane mirror (B). **Trace the path** of the ray until its reflection on mirror (B).

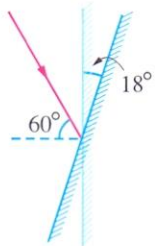
(b) **How** can the position of mirror (B) be modified to make the ray returns back parallel to the initial light ray ? (60°, 90°)



3 **Trace** the path of the incident light ray. If the angle between mirror A and mirror B equals 90°, **then calculate** the reflection angle of the light ray from mirror C if it is modified to be parallel to mirror A. (60°)



4 A light ray falls on a plane mirror at an angle of 60°. If the mirror is rotated by an angle of 18° in clockwise direction where the incident ray remains in the same direction of incidence as in the opposite figure, **what is the angle between** the reflected ray and the mirror ? (48°)



5 A light ray falls on the surface of a glass plate. If it makes an angle of 32° in air with the normal while it makes angle of 21° with the normal in the glass, **calculate** the refractive index of glass. (1.48)

6 If the refractive index of water is 1.3 and that of diamond is 2.4, **calculate :**

(a) The relative refractive index from diamond to water.

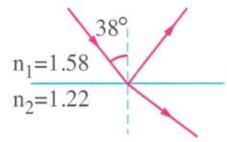
(b) The relative refractive index from water to diamond. (0.54, 1.85)

7 A light ray falls on the separating surface between two media. If the angle between the incident ray and the separating surface is 40° and the angle of refraction in the second medium is 30°, **calculate** the relative refractive index from the first medium to the second one. (1.53)

8 A light ray falls at an angle of 50° on a glass surface from air. If the speed of light in air is 3×10^8 m/s and in glass is 1.92×10^8 m/s, **calculate** the angle of refraction of the light ray in the glass. (24.29°)

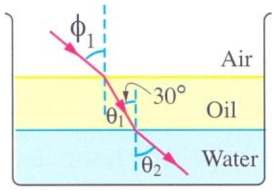
9 **From the opposite figure :**

Find the values of the angles of refraction and reflection. (38°, 52.88°)



10 The opposite figure shows the transfer of a light ray from air to oil then to water. If the absolute refractive index for oil is 1.48 and for water is 1.33, **calculate** the angles ϕ_1 , θ_2

(47.73° , 33.81°)



11 A light ray of frequency 4×10^{14} Hz falls from air on the plane surface of a glass piece; the refractive index of its material is 1.5. **Calculate** the wavelength of the light ray through the glass. (knowing that : the speed of light in air = 3×10^8 m/s) (5×10^{-7} m)

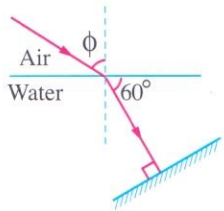
12 **In the opposite figure :**

A light ray falls on the separating surface between air and water then it reflects by a mirror under the water surface. **Find :**

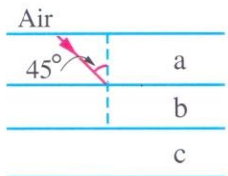
(a) The angle of incidence ϕ .

(b) The angle of refraction when emerging from water.

(knowing that : $n_{water} = 1.33$) (41.68° , 41.68°)



13 A light ray fell from air into three transparent layers a, b and c as in the opposite figure. If the speed of light in medium a is 1.4 of its speed in medium b, **calculate** the angle of incidence on the boundary surface between the two media c and b. (30.34°)

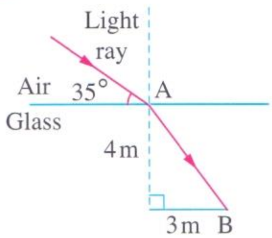


14 **From the opposite figure, calculate :**

(a) The refractive index for glass.

(b) The time taken by the ray of light to travel from A to B.

(knowing that : the speed of light in air = 3×10^8 m/s)



(1.37 , 2.28×10^{-8} s)

15 **How many** will additional minutes be taken by light to reach the Earth from the Sun, if the space between them is filled with water ?

(where : the average distance between the Earth and the Sun = 1.5×10^8 km, the refractive index of water = 1.33 and the speed of light in space = 3×10^8 m/s) (2.73 min.)

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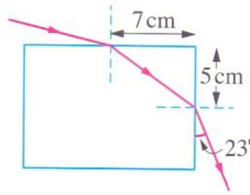
16 The opposite figure shows the path of a light ray through a glass cuboid, **calculate** the refractive index of glass. (1.58)



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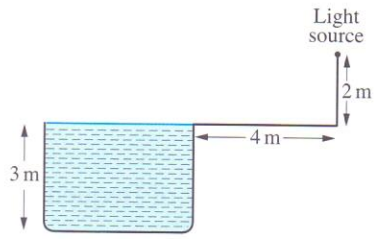
17 A swimming pool of depth 3 m is filled completely with water and to light the bottom of the swimming pool, a lamp is installed on a stand of height 2 m and at a distance 4 m from the edge of the swimming pool. **Calculate** the length of the dark part at the bottom of the swimming pool.

(where : the refractive index of water = $\frac{4}{3}$)



(2.71 m)

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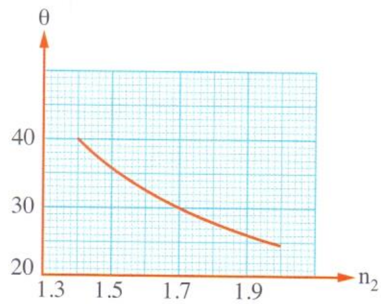
18 A light ray falls from a medium of refractive index n_1 at angle of incidence 30° on the boundary surface of another medium of refractive index n_2. If the opposite figure represents the change of the angle of refraction (θ) with the change of the refractive index of the second medium n_2, **calculate :**

(a) The absolute refractive index for the first medium (n_1).

(b) The angle of refraction in the second medium if the angle of incidence becomes 60° and the absolute refractive index for the second medium becomes 2.4



(1.7, 37.84°)

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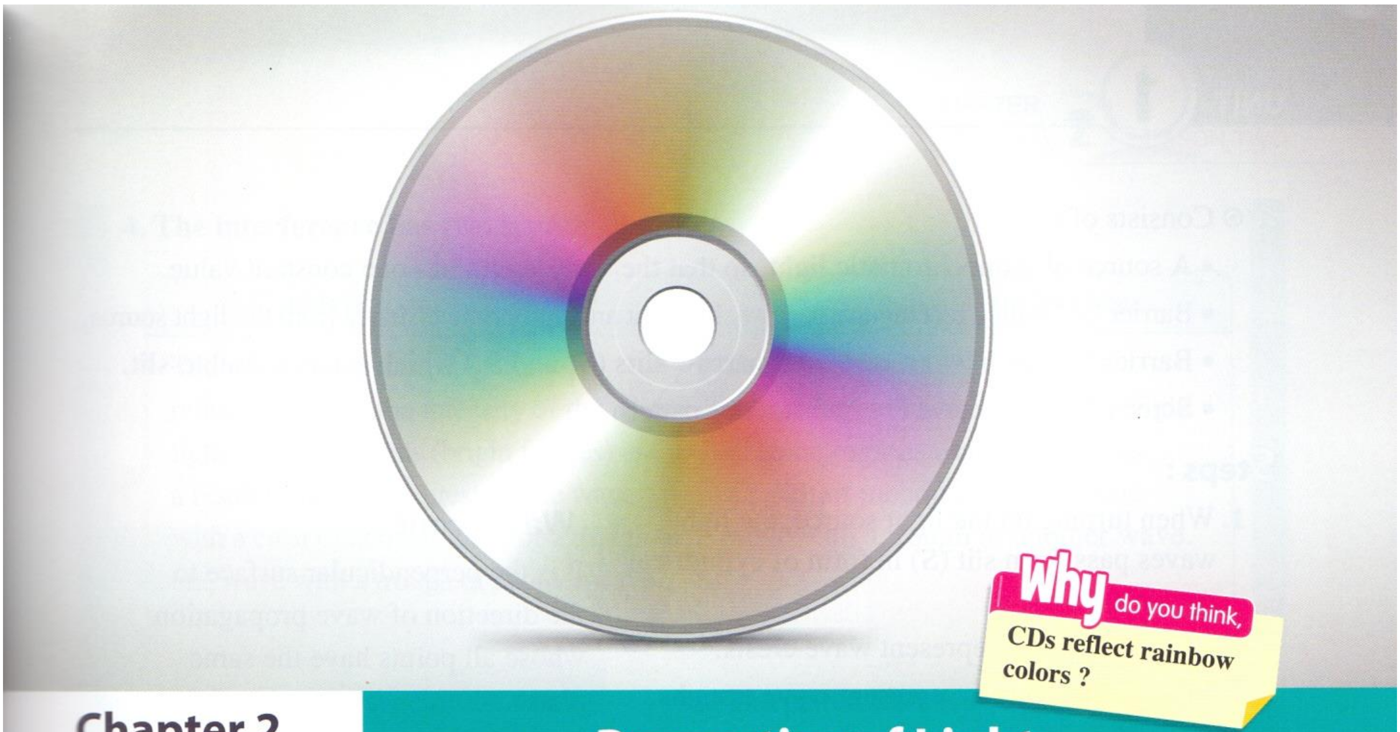
19 If a cuboid of glass, whose refractive index is $\sqrt{3}$, is placed above a plane mirror, then a light ray falls on the upper face of the cuboid with an angle 30° with the surface where it enters into the cuboid and reflected on the mirror then returns back to air, **show with drawing** the path of the ray and if the distance between the points of entering and emerging of the ray from the cuboid is 4 cm, **what** is the thickness of the cuboid ?

(3.46 cm)

---

20 A light ray fell at an angle of incidence 30° on the boundary surface between the air and the cornea of the eye of a swimmer. If the swimmer dove under water, **what** is the angle of incidence of a light ray in water that makes it refracts as if the swimmer was in air ?

(where : the refractive index of water = 1.33, the refractive index of cornea = 1.4) (22.08°)



Chapter 2

Lesson Two

Properties of Light
(Interference and Diffraction)

Fourth Light interference

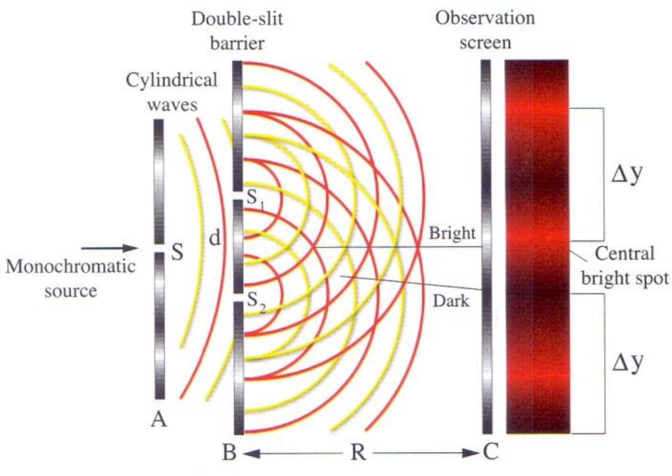
- To study the interference of light, we carry out the following experiment :

Thomas Young's double-slit Experiment

Objectives :

1. Proving the wave nature of light.
2. Investigating the phenomenon of light interference.
3. Determining the wavelength of a monochromatic (single wavelength) light.

Apparatus :



⊙ Consists of :

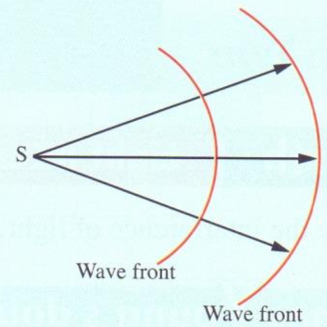
- A source of monochromatic light, so that the wavelength has one constant value.
- Barrier "A" with a rectangular narrow slit (S) at an appropriate distance from the light source.
- Barrier "B" with two rectangular narrow slits (S_1 and S_2) which act as a double-slit.
- Screen "C" to receive the interference pattern.

Steps :

1. When turning on the light source, the light waves pass from slit (S) in form of cylindrical waves, where :
   - The **red** curves represent wave crests.
   - The yellow curves represent wave troughs.
2. When light waves reach the two slits (S_1 , S_2) , the two slits (S_1 , S_2) will be at the same **wave front,** so they act as two **coherent sources,** *i.e.* They produce two coherent waves (have the same frequency, amplitude and phase).
3. The two waves from S_1 and S_2 propagate beyond the double slit barrier and when they reach the last screen they interfere with each other and give a pattern of **bright** (maxima) and **dark** (minima) regions which is known as the **interference pattern**.

Wave front :

It is the perpendicular surface to the direction of wave propagation whose all points have the same phase.



4. The distance between two successive fringes (Δy) of the same kind (bright or dark) can be determined from the relation : $\Delta y = \frac{\lambda R}{d}$

   Where : (λ) is the wavelength of the used light, (R) is the distance between the double-slit barrier and the observation screen and (d) is the distance between the two slits.

Conclusion :

1. Light rays interfere and produce an interference pattern which indicates that light propagates as waves.
2. The superposition of light waves of two coherent sources produces reinforcement of light in some regions (bright fringes) and weakness in other regions (dark fringes) and this phenomenon is known as **light interference**.
3. **Conditions of light interference :**
   - Each of the two light sources must be monochromatic.
   - The two light sources must be coherent (have the same frequency, amplitude and phase).

4. The interference has two types :

Constructive interference	Destructive interference
The interference that produces reinforcement in the intensity of the light in some regions (bright fringes) as a result of meeting a crest of one wave with a crest of another wave or a trough of one wave with a trough of another wave.	The interference that produces weakness in the intensity of the light in some regions (dark fringes) as a result of meeting a crest of one wave with a trough of another wave.
Its condition	
The path difference of the two interfered waves equals $m\lambda$.	The path difference of the two interfered waves equals $(m + \frac{1}{2})\lambda$.

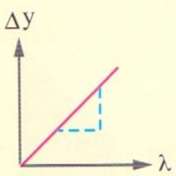
Where : m is the order of the fringe which is an integer number (0, 1, 2, ...).

5. The two waves which have equal path lengths give the central fringe which is always a bright fringe because the path difference at this fringe equals zero, so the interference becomes constructive.

The factors affecting the distance between two successive fringes of the same kind :

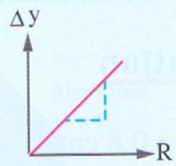
$$\Delta y = \frac{\lambda R}{d}$$

1 The wavelength of the used light "directly proportional".



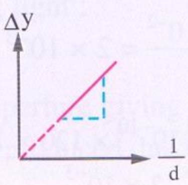
Slope $= \frac{\Delta(\Delta y)}{\Delta\lambda} = \frac{R}{d}$

2 The distance between the observation screen and the double-slit barrier "directly proportional"



Slope $= \frac{\Delta(\Delta y)}{\Delta R} = \frac{\lambda}{d}$

3 The distance between the two slits "inversely proportional".



Slope $= \frac{\Delta(\Delta y)}{\Delta(\frac{1}{d})} = \lambda R$

Example 1

In the double-slit experiment; if the distance between the two slits was 0.15 mm, the distance between the double-slit barrier and the observation screen was 75 cm and the distance between two successive bright fringes was 0.3 cm, calculate the wavelength of the used monochromatic light source.

Solution

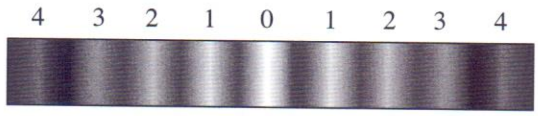
$d = 0.15\ \text{mm}$ | $\Delta y = 0.3\ \text{cm}$ | $R = 75\ \text{cm}$

$$\Delta y = \frac{\lambda R}{d}$$

$$\lambda = \frac{\Delta y d}{R} = \frac{0.3 \times 10^{-2} \times 0.15 \times 10^{-3}}{75 \times 10^{-2}} = 6 \times 10^{-7}\ \text{m} = 0.6\ \mu\text{m} = 6000\ \text{Å}$$

Example 2

The opposite figure represents the interference pattern of Young's experiment which was conducted with a light of wavelength 5000 Å and an observer screen at distance 120 cm from the double-slit. If the distance between the central fringe (0) and the fourth bright fringe (4) was 0.8 cm, calculate the distance between the two slits.



Solution

$x = 0.8\ \text{cm}$ | $N = 4$ | $\lambda = 5000\ \text{Å}$ | $R = 120\ \text{cm}$

Clue

To find the distance between two consecutive fringes of the same type (Δy) by using the distance (x) between any two fringes we use the following relation :

$$\Delta y = \frac{x\ (\text{Total distance})}{N\ (\text{Number of fringes})}$$

$$\Delta y = \frac{x}{N} = \frac{0.8 \times 10^{-2}}{4} = 2 \times 10^{-3}\ \text{m}$$

$$d = \frac{\lambda R}{\Delta y} = \frac{5000 \times 10^{-10} \times 120 \times 10^{-2}}{2 \times 10^{-3}} = 3 \times 10^{-4}\ \text{m}$$

4 Test yourself

A monochromatic light of wavelength 66×10^{-8} m fell on double-slits of separation distance 11×10^{-4} m , so interference fringes were formed on an observation screen which was at a distance 1 m from the double-slit barrier.

Calculate the distance between the centers of two successive fringes of the same type.

....

....

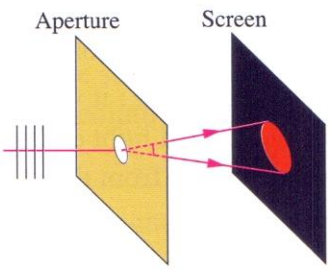
....

Fifth Light diffraction

What happens if a monochromatic light fell on a small aperture of a barrier whose size is comparable to the wavelength of the falling light ?

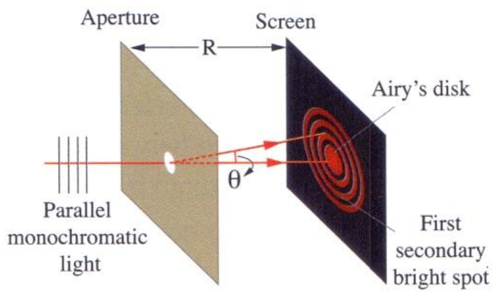
Expectation

- It is expected that a small spot of light will appear on the screen.



Reality

- But what really happens is that a bright spot of light which is called Airy's disk appears at the center surrounded by alternated bright and dark rings. This phenomenon happens as a result of light diffraction.



Diffraction on a circular aperture

⊙ Explanation :

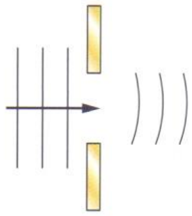
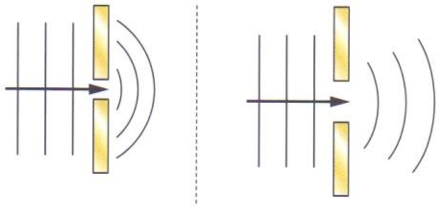
When monochromatic light waves fall on the edge or on a circular aperture of a barrier whose size is comparable to the wavelength of the falling light :

- They change their direction of propagation (diffract).
- They interfere with each other (superpose) behind the aperture giving diffraction fringes which are a pattern of alternate bright and dark regions produced due to the superposition of the diffracted light waves.

⊙ The condition of the clear appearance of light diffraction :

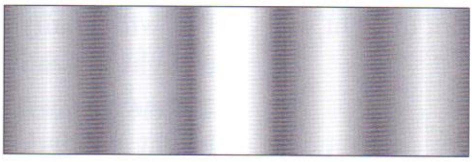
The wavelength of the light wave has to be relatively close in size to the dimensions of the aperture and vice versa.

So, if the aperture size is :

a lot bigger than the wavelength of light	comparable to the wavelength of light
	
The diffraction doesn't appear.	The diffraction appears and becomes more clearer by the decrease of the aperture size.

Notes :

1. When light falls on a rectangular narrow aperture, it suffers diffraction and the diffraction fringes appear as a pattern of lateral distributed bright and dark fringes with a central wide bright fringe as shown in the figure :

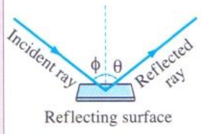
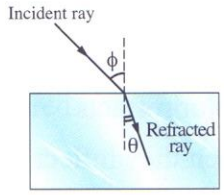
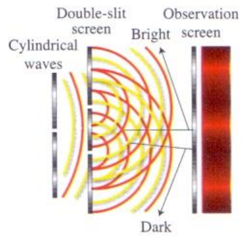
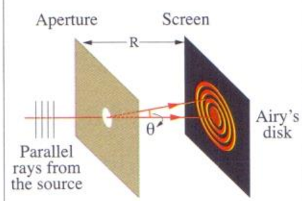


2. The range of wavelengths of visible light extends from 400 nm to 700 nm which are very small wavelengths so that light diffraction doesn't appear in our daily life because visible light needs very small aperture sizes for the appearance of light diffraction patterns.
3. From the study of light interference and light diffraction phenomena ; it was found that there is no big difference between the light interference model and light diffraction model because each of them is a wave phenomenon which results from the superposition of waves.

☆ The wave properties of light can be summarized as the following :

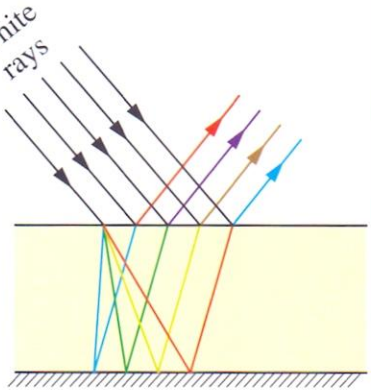
1. Light rays propagate in straight lines in the homogeneous medium.
2. They reflect when they fall on a reflecting surface, according to the laws of reflection.
3. They refract when they travel between two transparent media of different optical densities, according to the laws of refraction.
4. Light waves interfere when they meet other waves that have the same frequency, amplitude and phase producing regions of constructive interference (maxima) and regions of destructive interference (minima).
5. They diffract in the same medium when they pass through slits or by sharp edges that have dimensions near in size to the wavelength of falling the light waves.

The phenomena of reflection, refraction, interference and diffraction of light waves can be compared as follows :

Points of Comparison	Reflection	Refraction	Interference	Diffraction
Form :				
Definition :	The bouncing of light in the same medium when it meets a reflecting surface.	The change in the direction of light path when they pass the separating surface between two transparent media which are different in the optical density.	The superposition of waves produced from two coherent sources, producing bright fringes in some regions and dark fringes in other regions.	The change in the direction of the wave path when passing through a narrow slit or an aperture leading to the superposition of waves and the formation of bright fringes and dark fringes.
Occurrence :	At the reflecting surface in the same medium.	At the boundary surface between two media which are different in the optical density.	In the same medium behind the double-slit barrier.	At a slit or a sharp edge in the same medium.
Condition :	The light waves fall on a reflecting surface.	The two transparent media have different optical densities.	- The two waves must come from two monochromatic sources. - The sources must be coherent (have the same frequency, amplitude and phase).	The wavelength of the light waves must be near to the size of the slit.

Learn for leisure

⊙ Why do CDs reflect rainbow colors ?



- CDs are made of a reflecting surface coated by a transparent layer (thin film).
- White light is composed of a range of different wavelengths (different colors).
- When white light falls on a CD, each color refracts with a different angle in the thin film then they reflect on the reflecting surface of the CD.
- When the rays of light reach the surface of the thin film they interfere with the white rays that are reflecting from the surface of the thin film.
- Each color interfere with its similar color at the surface of the thin film and that leads to the formation of rainbow colors on the CD.
- The same phenomenon happens in water and soap bubbles.

QUESTIONS ON
Chapter 2
LESSON TWO

Properties of Light
(Interference and Diffraction)

Interactive test

First Multiple choice questions

1 In Young's double-slit experiment, the separation distance between the two slits was 10^{-4} m and the distance between two consecutive fringes of the same type was found to be 3.75 mm when they appeared on an observation screen at a distance 0.75 m from the two slits, so the wavelength of the used light equals ....

(a) 5000 Å (b) 5400 Å (c) 6000 Å (d) 6400 Å

2 In Young's experiment; the path difference between the two rays coming from the two slits to the first dark fringe equals ....

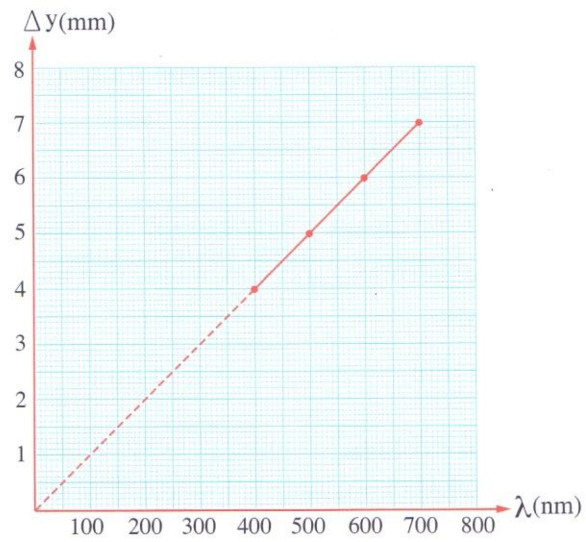
(a) λ (b) 2λ (c) $\frac{\lambda}{2}$ (d) 0

3 The ratio between the width of the central bright fringe when conducting Young's double-slit experiment with red light and its width when using violet light is ....

(a) greater than one (b) less than one

(c) equal to one (d) indeterminable

4 The opposite graph shows the relation between the wavelength of the used light in Young's double-slit experiment (λ) and the distance between the central fringe and the first bright fringe (Δy), so the ratio $\frac{R}{d}$ = ...



(a) 10^4

(b) 10^{-4}

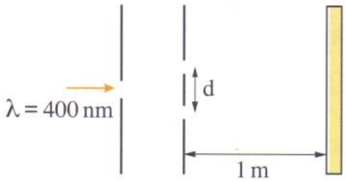
(c) 2×10^4

(d) 10^9

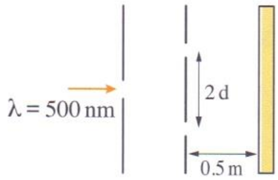
5. In Young's double-slit experiment, the width of the interference fringes increases when ....

(a) the distance between the double-slit and the screen decreases
(b) the distance between the double-slit and the screen increases
(c) the distance between the two slits increases
(d) the wavelength of the used monochromatic light decreases

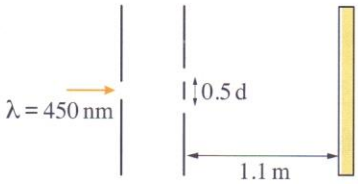
6. Which of the following diagrams of Young's double-slit apparatus will yield the best noticeable interference fringes ? ....



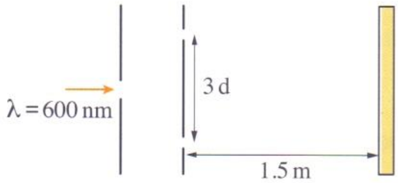
(a)



(b)



(c)



(d)

7. In Young's double-slit experiment, if $R = 10^4$ d, then ....

(a) $\Delta y = \lambda$ (b) $\Delta y = 10^4 \lambda$ (c) $\Delta y = 10^{-4}$ (d) $\Delta y = \frac{\lambda}{10}$

8. In Young's double-slit experiment, if the distance between the centers of the fifth bright fringe (maxima) and the central fringe is x, so the distance between the centers of the second dark fringe (minima) and the central fringe is ....

(a) $\frac{3}{10}$ x (b) $\frac{2}{5}$ x (c) $\frac{3}{2}$ x (d) $\frac{2}{7}$ x

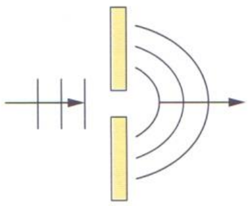
9. If the distance between the first maxima and the central fringe in Young's double-slit experiment is 2 mm, so the distance between the third minima and the central fringe equals ....

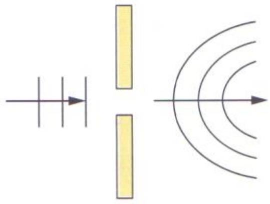
(a) 2 mm (b) 5 mm (c) 6 mm (d) 7 mm

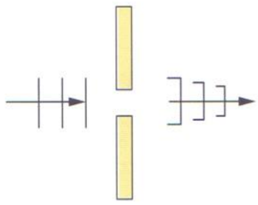
10. In a Young's double-slit experiment, the fringe width is found to be 0.4 mm. If the whole apparatus is immersed in water of refractive index $\frac{4}{3}$ without disturbing the geometrical arrangement, the new fringe width will be ....

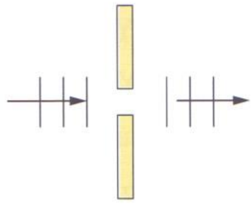
(a) 0.3 mm (b) 0.4 mm (c) 0.53 mm (d) 450 microns

11 Which of the following diagrams represents correctly the phenomenon of light diffraction when light falls on an aperture ? ....


(a)


(b)


(c)


(d)

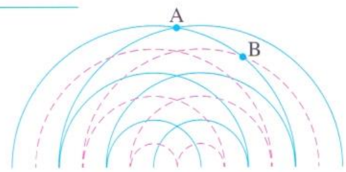
12 Light waves fall on different apertures of different sizes, so the diffraction of light will be most observable if the aperture size is ....

(a) 1 m (b) 10^{-2} m (c) 10^{-3} m (d) 10^{-5} m

Second Essay questions

1 **How** to get a high noticeable interference pattern in Young's double-slit experiment ? **Explain your answer.**

2 **What** are the types of interference at point A and B ?



3 Young's double-slit experiment is conducted by using red light, **what** happens to the distance between the interference fringes, if :

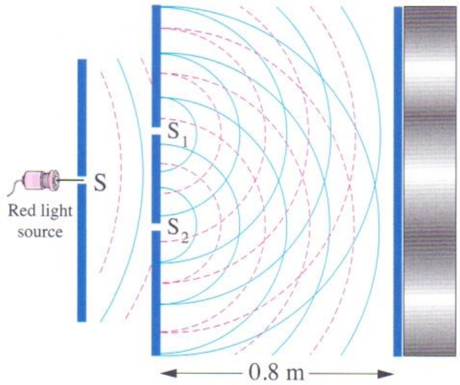
(a) the distance between the slits decreased?

(b) a blue light is used instead of red?

(c) the frequency of the used light decreased?

(d) the observation screen is displaced away from the slits?

4 The opposite figure represents Young's double-slit experiment which is conducted by using red light of wavelength 700 nm and a barrier of two slits which are separated by a distance 2 mm, so the interference pattern is observed on a screen at a distance 0.8 m from the double-slit :



(a) **What** did Thomas Young confirm by this experiment?

(b) **Why** did Thomas Young use a monochromatic light?

(c) **How** did Thomas Young get two coherent light sources from one source?

(d) **Calculate** the distance between the central fringe and the first bright fringe.

5 **Explain the following statements :**

(1) The central fringe in Young's double-slit experiment is always bright.

(2) Light diffraction has not been observed when a monochromatic light waves fell on a circular aperture.

(3) There is no big difference between the phenomena of interference and diffraction of light.

6 A double-slit is lighted by a blue light, so bright and dark fringes are observed as the following figure :

(a) **Which** of the appearing fringes on the figure is the central fringe ?

(b) **Why** do these fringes appear ?

Third Problems

1 In Young's double-slit experiment, if the distance between two coherent sources was 1.6 mm where the fringes were formed on a screen at distance 60 cm from the two sources and the third bright fringe was at 0.6 mm from the central fringe, **find** the wavelength of the used light. $(5.33 \times 10^{-7}$ m)

2 An experiment is conducted to study the interference of light by using the double-slit apparatus, where the distance between the double slit barrier and the observation screen was 2 m, when changing the distance between the two slits (d), the width of the fringes (Δy) is changing as recorded in the following table :

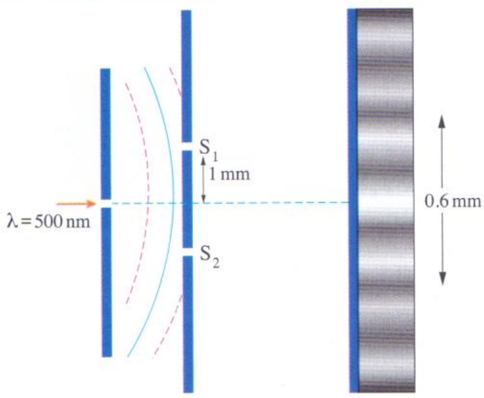
$d \times 10^{-3}$ (m)	5	4	2.5	2	1
$\Delta y \times 10^{-4}$ (m)	2	2.5	4	5	10

(a) **Plot** the relation between the fringe width (Δy) on y-axis and the reciprocal of the distance between the two slits ($\frac{1}{d}$) on x-axis.

(b) **From the graph find** the wavelength of the used light. (5×10^{-7} m)

3. **Calculate** the frequency of light which is used in Young's experiment, if the distance between the two narrow slits is 0.00015 m, the distance between the observation screen and the double-slit is 0.75 m , and the distance between two successive bright fringes is 0.002 m. (knowing that : the speed of light in air = 3×10^8 m/s) (7.5×10^{14} Hz)

4. **Calculate** the distance between the double slit barrier and the observation screen in Young's double-slit experiment which is shown in the opposite figure. (0.8 m)



5. In Young's double-slit experiment, the separation between the centers of two successive interference fringes of the same type for the green light is 0.275 mm and its wavelength is 550 nm. When red light of wavelength 600 nm is used or violet of wavelength 400 nm, different fringes were obtained, **find :**

(a) The distance between the centers of two successive interference fringes of the same type for the red light.

(b) The distance between the centers of two successive interference fringes of the same type for the violet light.

(0.3 mm, 0.2 mm)

6. In Young's double-slit experiment, if the wavelength of the used light changed from 400 nm to 600 nm, and the distance between the central fringe and the first minima increased by 0.01 mm, **calculate** the distance between the central fringe and the second maxima in the first case. (0.08 mm)

7. A red light of wavelength 6000 Å fell on a double-slit separated by a distance 0.02×10^{-2} m, so an interference pattern appeared on a screen 1 m away from the two slits. If the red light is replaced by violet light of wavelength 4000 Å, **what** is the order of the bright fringe of the violet light which has the same position as the second bright fringe of the red light ? (3)

Chapter 2

Lesson Three

Total Internal Reflection

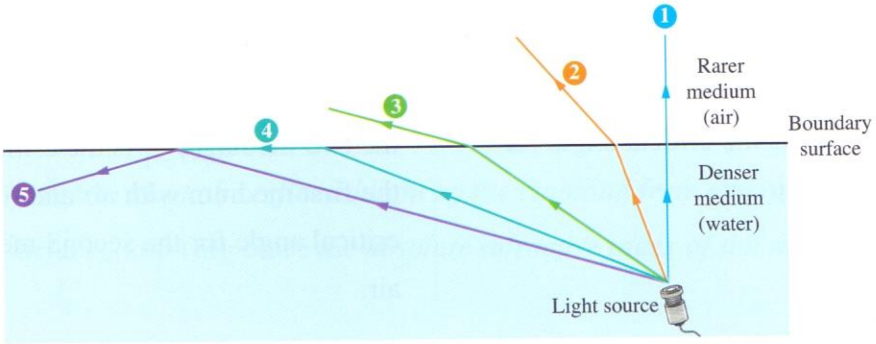
- Light refraction phenomenon is used to explain the occurrence of the following phenomena :
  - The total internal reflection.
  - The deviation of light in a triangular prism.
- In this lesson, we will study the total internal reflection of light in some details.

Total internal reflection

Occurrence :

- When a light ray falls from an optically denser medium (such as water or glass) on the boundary surface of an optically less dense (rarer) one (such as air) :

1	If the light ray fall perpendicularly on the surface ($\phi = 0$)	The light ray enters into the optically rarer medium without any refraction.
2	If the angle of incidence is increased to be greater than zero ($\phi > 0$)	The light ray enters into the optically rarer medium and refracts away from the normal.
3	By increasing the angle of incidence of light gradually ($\phi >> 0$)	The angle of refraction (θ) in the optically rarer medium increases gradually as $\sin \theta = n \sin \phi$
4	At a definite angle of incidence that is known as critical angle (ϕ_c)	The angle of refraction (θ) equals 90° and the light ray refracts tangentially to the boundary surface.
5	When the angle of incidence becomes greater than the critical angle ($\phi > \phi_c$)	The light ray reflects back in the optically denser medium (where the angle of incidence = The angle of reflection).



From the previous we can conclude that :

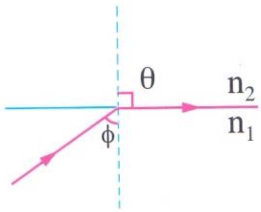
1. The critical angle between two media (ϕ_c) is the angle of incidence of the ray in the denser medium which lead to a refraction angle of 90° in the rarer medium.
2. Critical angle (ϕ_c) depends on :
   (a) The types of the two media.
   (b) The wavelength of the incident light ray.
3. The total internal reflection is the reflection of light rays in the denser medium when the angle of incidence becomes greater than the critical angle for the two media.

Deducing the relation between the critical angle and the refractive index of a medium :

- Applying Snell's law :

$\because n_1 \sin \phi = n_2 \sin \theta$

When the ray falls with an angle that equals the critical angle :



$\because \phi = \phi_c \quad , \quad \theta = 90°$

$\therefore n_1 \sin \phi_c = n_2 \sin 90°$

$\therefore n_1 \sin \phi_c = n_2$

$$\therefore \boxed{\sin \phi_c = \frac{n_2}{n_1} = {}_1n_2}$$

If the rarer medium is :

Air ($n_{air} = 1$)	Not air

So,

Air:

$n_2 = 1 \quad , \quad n_1 = n$

$\therefore n \sin \phi_c = 1$

$$\therefore \boxed{\sin \phi_c = \frac{1}{n}}$$

Not air:

$n_1 \sin \phi_c = n_2$

$$\therefore \boxed{\sin \phi_c = \frac{n_2}{n_1} = {}_1n_2 = \frac{\sin (\phi_c)_1}{\sin (\phi_c)_2}}$$

Where :

(n) is the refractive index of the denser medium and (ϕ_c) is the critical angle for the medium and air.

$n_1 > n_2$, ϕ_c is the critical angle between the two media, $(\phi_c)_1$ is the critical angle for the first medium with air and $(\phi_c)_2$ is the critical angle for the second medium with air.

Example 1

If the absolute refractive indices of glass and water are 1.6 and 1.33 respectively, calculate :

(a) The critical angle of each of them with air.

(b) The critical angle for the incident light ray that travels from glass to water.

Solution

$n_1 = 1.6$ $n_2 = 1.33$

(a) In case of glass and air : $\sin (\phi_c)_1 = \frac{1}{n_1} = \frac{1}{1.6}$

$(\phi_c)_1 = 38.68°$

In case of water and air : $\sin (\phi_c)_2 = \frac{1}{n_2} = \frac{1}{1.33}$

$(\phi_c)_2 = 48.75°$

(b) $n_1 \sin \phi_c = n_2 \sin 90$

$\sin \phi_c = \frac{n_2}{n_1} = \frac{1.33}{1.6}$

$\phi_c = 56.23°$

Example 2

The speeds of propagation of two light rays through two different media (x and y) are 2×10^8 m/s and 2.75×10^8 m/s respectively.

Calculate the critical angle between the two media.

Solution

$v_x = 2 \times 10^8$ m/s $v_y = 2.75 \times 10^8$ m/s

$\sin \phi_c = \frac{n_y}{n_x} = \frac{v_x}{v_y} = \frac{2 \times 10^8}{2.75 \times 10^8}$

$\phi_c = 46.66°$

Example 3

A piece of diamond was placed in the bottom of a basin filled with water at a depth of 1 m, calculate the smallest diameter of a cork disc that floats on the water surface, which is enough to block the reflected light by the diamond from emerging out of the water surface. (knowing that : the absolute refractive index of the water = 1.33)

Solution

$n_w = 1.33$ $h = 1\text{ m}$

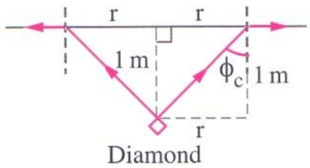
Clue

The smallest disc that can block the reflected light from the diamond has to be put on the water surface in such away that when the angle of incidence of the light ray equals the critical angle, the light ray doesn't emerge from the water surface.

$\because \sin \phi_c = \frac{1}{n_w} = \frac{1}{1.33}$, $\therefore \phi_c = 48.75°$

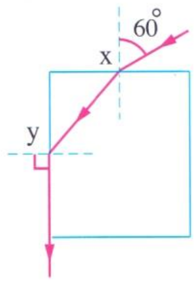
$\because \tan 48.75 = \frac{r}{h} = \frac{r}{1}$, $\therefore r = 1.14\text{ m}$

$\therefore$ The diameter of the disc = 2 r = 2.28 m



Example 4

The opposite figure shows a light ray which falls on a glass slab at point x and emerges tangentially to the other face at point y. Calculate the refractive index of the glass slab. (knowing that : sin (90 – θ) = cos θ)



Solution

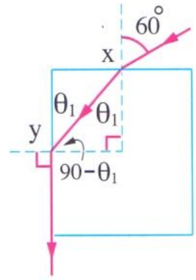
$\phi_1 = 60°$ $\theta_2 = 90°$

From the figure we find :

$\phi_c = 90 - \theta_1$

$\because n = \frac{\sin \phi}{\sin \theta}$ $\therefore n = \frac{\sin 60}{\sin \theta_1}$ (1)

$n = \frac{1}{\sin \phi_c} = \frac{1}{\sin (90 - \theta_1)} = \frac{1}{\cos \theta_1}$ (2)



From (1) and (2) :

$$\frac{\sin 60}{\sin \theta_1} = \frac{1}{\cos \theta_1}$$

$$\frac{\sin \theta_1}{\cos \theta_1} = \tan \theta_1 = \sin 60$$

$\therefore \theta_1 = 40.89°$

By substituting in equation (1) :

$$n = \frac{\sin 60}{\sin 40.89} = 1.32 \text{ m}$$

5 Test yourself

(1) A light ray fell from glass on the boundary surface with water, so its wavelength changed from 5000 Å to 5625 Å, **calculate** the critical angle from glass to water.

....

....

....

(2) If the critical angle for glass with air is 41.81° and the critical angle for water with air is 48.59°, **calculate** the critical angle of glass with water.

....

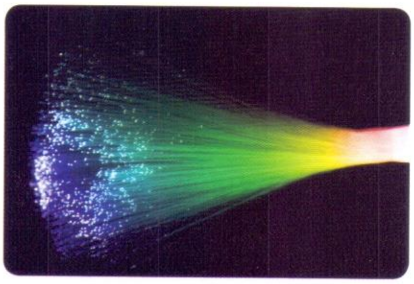
....

....

Applications of the total internal reflection of light :

1. Optical fibers (fiberoptics).
2. The reflecting prism.
3. The mirage.

1 Optical fibers (fiberoptics)



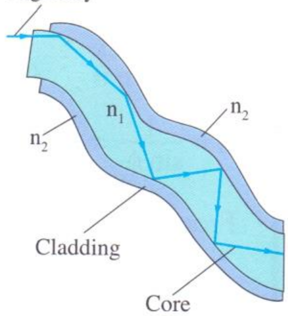
Structure :

It is a thread-like tube of transparent elastic material, which can be bent while containing light and can be made of a bundle of fibers.

Idea of working : Total internal reflection.

Explaining the idea of working :

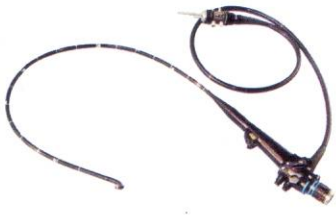
When a light ray falls on any part of the internal wall of the optical fiber with an angle of incidence greater than the critical angle, it undergoes multiple successive reflections until it emerges from the other end without much losses in the intensity of light despite of bending the fiber.



Usage :

1. Transferring light to parts which are hard to reach.
2. Transmitting light in non-straight paths without much losses in the light intensity.

3. They are widely used nowadays in medical examination devices such as medical endoscopes, which are used in :
   - Diagnosis.
   - Operative surgery using laser beam.
4. Communication as light can carry millions of electric signals in optical fiber cables.

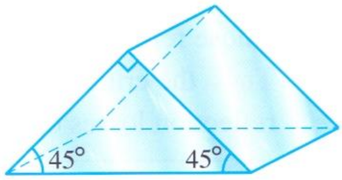


Note :

- Optical fibers that have two layers are preferred to the optical fibers that have only one layer because the external layer has lerger refractive index than the internal layer so it reflects any part of light that may escape from the internal layer by total internal reflection so that light is kept travelling inside the fiber and its intensity doesn't decrease, which means that the fiber of two layers is more efficient for transferring light to long distances.

2 Reflecting prism

⊙ Structure :
A triangular glass prism whose angles are 45° , 45° and 90° which is made of glass of refractive index 1.5
i.e. its critical angle with air is 41.8° (≈ 42°).

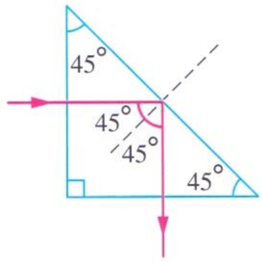


⊙ Idea of working : Total internal reflection.

⊙ Usage :

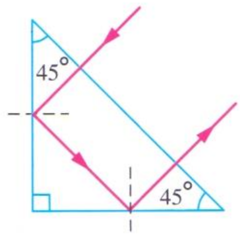
1 Changing the path of the light ray by 90°

- When a light ray falls normally on one of the right-angled faces of the prism, it passes straight and falls on the opposite side to the right angle by an angle 45°.
- Since the critical angle between the glass and the air is 42°, then the light ray will be reflected totally by an angle 45°.
- The reflected light ray falls normally on the other right-angled face and passes without refraction.

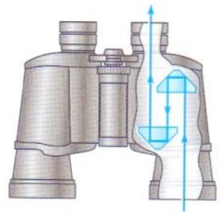


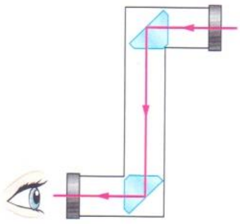
2 Changing the path of the light ray by 180°

- When a light ray falls normally on the opposite face to the right angle, it passes straight and falls on one of the right-angled faces by an angle 45°.
- Since the critical angle between the glass and the air is 42°, then the light ray will be reflected totally by an angle 45°.
- The reflected light ray falls on the other right-angled face by an angle 45° and reflects by an angle 45°.
- The reflected light ray falls normally on the opposite face to the right angle and passes without refraction.



So, the reflecting prism is used in some optical instruments such as :
- Submarines periscope.
- Field binocular.


Binocular


Periscope

Notes :

1. The reflecting prisms are preferred to the metallic reflecting surfaces or mirrors in some optical instruments for the following reasons :

   ① Because they reflect light totally while it is seldom to find a metallic reflecting surface whose efficiency is 100 %

   ② In addition a metallic surface eventually loses its luster and hence its ability of reflection decreases, this does not happen in a prism.

2. The surfaces at which light rays fall on a prism or emerge from it, are coated with non-reflective layer of a material like cryolite (aluminum fluoride and magnesium fluoride) whose refractive index is less than that of glass.
   Thus, the critical angle between the glass and cryolite becomes small to avoid any reflection losses on the prism and increase its efficiency.

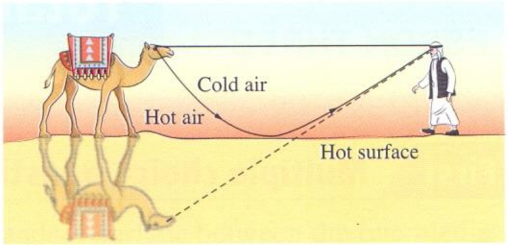
3 Mirage

- During hot days the roads seem to be covered with water.
- Hills and palms appear as inverted pictures such as the picture formed due to reflection on water surface. So, the observer thinks that there is water on the road and this phenomenon is known as **mirage**.

Explanation of mirage phenomenon :

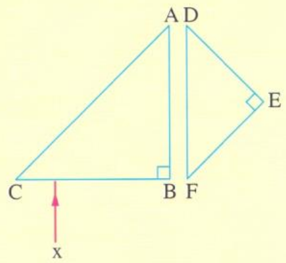
- In extremely hot days, the temperature of air layers adjacent to the Earth's surface increases so that its density decreases more than the upper layers. Accordingly the refractive indices of the upper layers become larger than the lower layers ($n_1 > n_2$).
- When a light ray passes from the upper air layers (optically denser layers) to the lower air layers (optically rarer layers), it refracts away from the normal according to Snell's law, where $\left(\frac{\sin\phi}{\sin\theta} = \frac{n_2}{n_1}\right)$.
- The deviation of the light ray increases when it passes through air layers taking a curved path.

- When the angle of incidence of the light ray in one layer becomes larger than the critical angle of the following layer, the light ray reflects totally taking curved path upwards until reaching the observer's eye. So, the eye sees the image (top of the camel) inverted on the extension of the light rays that reach the eye and the observer thinks that there is water on the ground.



6 Test yourself

Choose : The opposite figure shows two triangular prisms that reflect ray x when it falls perpendicularly on the face BC, so the ray will emerge from face ....



(a) AC (b) DE

(c) EF (d) BC

QUESTIONS ON
Chapter 2
LESSON THREE

Total Internal Reflection

Interactive test

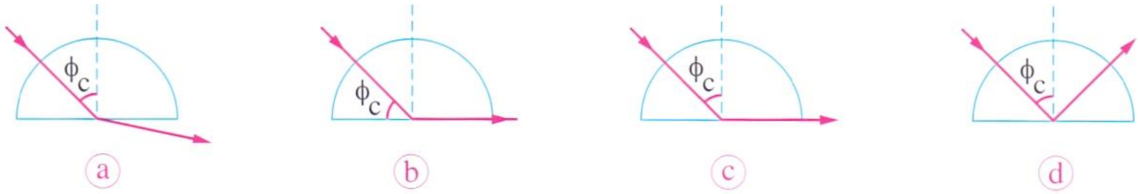
First Multiple choice questions

1 The total internal reflection for an incident light ray from an optically denser medium to an optically rarer medium, occurs when the angle of incidence is ....

(a) equal to 90°
(b) bigger than the critical angle
(c) equal to the critical angle
(d) less than the critical angle

---

2 Figure .... represents the correct path of incident light ray on a semi-circular disc of glass with an angle of incidence equals the critical angle (ϕ_c).



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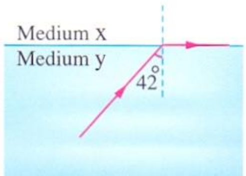
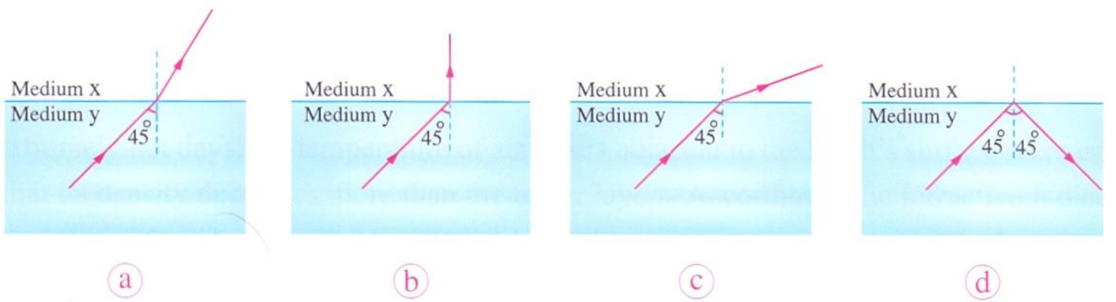
3 In the opposite figure :

If the angle of incidence becomes 45°, which of the following figures represents the correct path of the ray? ....





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4 The biggest refraction angle for a light beam falling from water of refractive index $\frac{4}{3}$ to air is ....

(a) 41.82°
(b) 48.59°
(c) 90°
(d) 180°

5 The critical angle between two media depends on ....

a the refractive index of the optically denser medium

b the refractive index of the optically rarer medium

c the refractive indices of the two media

d the angle of incidence of the light ray on the boundary surface between the two media

6 If the critical angle for a medium with respect to air is 42°, the refractive index of this medium equals ....

a $\sqrt{2}$ b 1.73 c 1.64 d 1.49

7 If the refractive index of glass is $\sqrt{2}$, the biggest angle of incidence that lets a light ray emerges from glass to air equals ....

a 30° b 45° c 60° d 75°

8 If the critical angle from a glass slab of refractive index 1.52 to another medium of refractive index n is 45°, the refractive index (n) equals ....

a 1 b 1.07 c 1.33 d 1.52

9 A container of glass of refractive index 1.65 contains a liquid of refractive index 1.32, so the critical angle between them is ....

a 37.31° inside the glass b 37.31° inside the liquid

c 53.13° inside the glass d 37.31° inside the liquid

10 If the critical angle from medium a to medium b is ϕ_c and the speed of light in medium a is v, the speed of light in medium b is ....

a $v \sin \phi_c$ b $v \cos \phi_c$ c $\frac{v}{\cos \phi_c}$ d $\frac{v}{\sin \phi_c}$

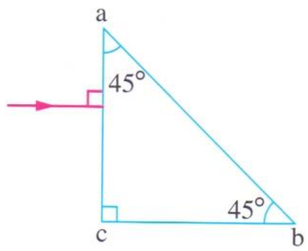
11 A light ray falls at an angle 54° from air on the surface of a transparent medium, so a part of the ray is reflected and other part is refracted. If the reflected and the refracted rays are perpendicular on each other, the critical angle for the transparent medium with air is ....

a 28.4° b 35.4° c 42.4° d 46.4°

12 If $n_{glass} > n_{water} > n_{gasoline}$, so the ratio between the critical angle of glass with water and the critical angle of glass with gasoline is ....

a less than 1 b greater than 1 c equal to 1 d indeterminable

13 In the opposite figure :



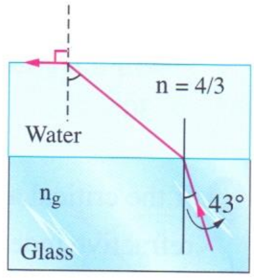
(i) If the refractive index of the prism is 1.5, the falling ray on face ab ....

a) emerges with an angle 45°
b) emerges with an angle 60°
c) emerges with an angle 90°
d) undergoes total internal reflection

(ii) If the refractive index of the prism is $\sqrt{2}$, the falling ray on face ab ....

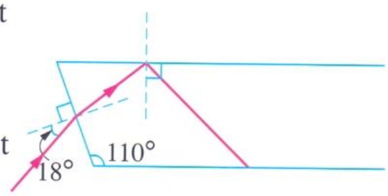
a) undergoes total internal reflection
b) emerges with an angle 60°
c) emerges with an angle 82°
d) emerges tangentially to that face

14 A ray of light is incident at the glass-water interface at an angle 43°, it emerges finally parallel to the surface of water, so the value of n_g is ....



a) 1.33
b) 1.47
c) $\sqrt{3}$
d) 1.1

15 A light ray from air is incident (as shown in the figure) at one end of a glass fiber making an incidence angle of 60° on the lateral surface, so that it undergoes a total internal reflection. If this light ray takes 12 μs to traverse the straight fiber, what is the length of the fiber ? ....



a) 2.03 km
b) 3.33 km
c) 1.76 km
d) 3.76 km

16 A fish looks from within water of refractive index $\frac{4}{3}$ and sees the outside world through a circular horizon. If the fish is $\sqrt{7}$ cm below the surface of water, what will be the radius of the circular horizon ....

a) 3 cm
b) 4 cm
c) 4.5 cm
d) 5 cm

17 A point source of light is placed 4 m below the surface of water of refractive index $\frac{5}{3}$, so the minimum diameter of a disc that should be placed over the source on the surface of water to cut off all light coming out of water is ....

a) 2 m
b) 6 m
c) 4 m
d) 3 m

18 If light travels a distance X in t seconds in air and 2 X in 3 t seconds in a medium, the critical angle of the medium is ....

a) 62.4°
b) 48.1°
c) 41.8°
d) 30.6°

19 Glass has refractive index n with respect to air and the critical angle for a ray of light going from glass to air is γ. If a ray of light is incident from air on the glass with angle of incidence γ, the corresponding angle of refraction is ....

(a) $\sin^{-1}\left(\frac{1}{\sqrt{n}}\right)$ (b) 90° (c) $\sin^{-1}\left(\frac{1}{n^2}\right)$ (d) $\sin^{-1}\left(\frac{1}{n}\right)$

20 The speed of light in a medium is half its speed in air. If a ray of light falls from such medium on the interface with air, the least angle of incidence, at which the ray is totally internally reflected, is ....

(a) 15° (b) 30° (c) 45° (d) 60°

21 For total internal reflection to take place, the angle of incidence ϕ and the refractive index n of the medium must satisfy the inequality ....

(a) $\frac{1}{\sin\phi} < n$ (b) $\frac{1}{\sin\phi} > n$ (c) $\sin\phi < n$ (d) $\sin\phi > n$

Second Essay questions

1 **Explain the following statements :**

(1) Despite of the falling of a light ray from an optically denser medium to an optically rarer medium, it doesn't undergo total internal reflection.

(2) When light is emitted from beneath the surface of water, it might not be seen in air.

(3) Optical fibers are used to transfer light.

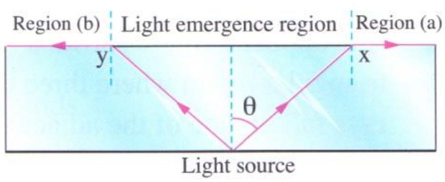
(4) Optical fibers are used in medical endoscopes.

(5) Prisms are preferred to mirrors as reflectors in some optical instruments.

(6) The appearing of mirage in hot deserts.

2 Four light rays are emitted from light sources under the surface of a liquid of refractive index 1.39. If the first ray falls perpendicularly on the surface of the liquid, the second falls at an angle of incidence 30°, the third at 46° and the fourth at 60°, **describe what happens for each ray**.

3 The opposite figure shows a light source in the bottom of water container.

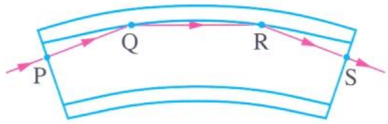


(a) **Why** doesn't light emerge from regions (a) and (b) ?

(b) **Calculate** the value of the angle θ.

(where : the refractive index of water = 1.33)

4 **In the opposite figure :**
An optical fiber is coated by a thin film whose refractive index is less than that of the fiber's core. If a light beam passes through it as shown in the figure, **explain why :**



(a) the direction of the beam does not change at each of S and P.

(b) there is a total reflection at each of Q and R.

(c) the double layer in the optical fiber is preferred to that of a single layer.

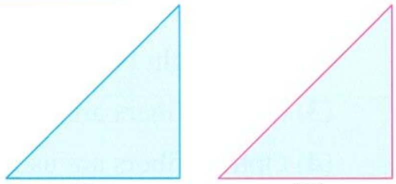
5 When a blue light source was placed in the center of a cube of glass which is surrounded by white observation screens such that each screen faces one of the lateral sides of the cube, a circular bright blue spot appeared on each screen and when the blue light source is replaced with a red light source the shape of the spot has changed and it becomes a square red spot. **Explain why** the shape of the spot changed.

6 Three light sources were placed in the bottom of water basin which is covered with a white sheet, the first source gives a yellow light, the second gives red light and the third gives blue light. When the three sources are switched on, three circular light spots of different areas have appeared on the white sheet. **Arrange** the sources ascendingly according to the area of the spot on the sheet and **explain why** each light source has different spot area.

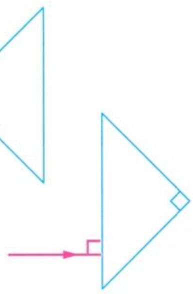
7 The opposite figure shows two reflecting prisms where prism (2) is coated with a non-reflective thin film.

(a) **What** is the type of the material of the thin film ?

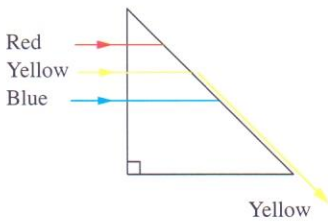
(b) **Which** of the two prisms is more efficient ? **And why ?**



8 The opposite figure shows two reflecting prisms. If a light ray falls perpendicularly on a face of one of them, **trace** the path of the ray until it emerges from the other prism.



9 The opposite figure shows a right angled isosceles triangular prism where three different colors of light rays fall on one of the adjacent faces to the right angle. So if the yellow ray emerges tangentially to the opposite face of the right angle, **trace** the path of the other red and blue rays, **with explanation**.



Third Problems

1. If the refractive index of diamond is 2.5, **calculate** its critical angle with air. (23.58°)

2. A light ray falls on a liquid surface. If the angle of incidence is 30° and the angle of refraction is 22°, **calculate** the critical angle for the ray when it passes from the liquid to air. (48.51°)

3. If the speed of light in air is 3×10^8 m/s and in another medium is 1.33×10^8 m/s, **calculate** the critical angle of that medium with air. (26.32°)

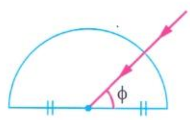
4. **Find** the critical angle of a light ray that passes from water which has a refractive index 1.333 to snow whose refractive index is 1.309. (79.11°)

5. Two media are different in their optical density. If the critical angle between them is 50° and the absolute refractive index for the optically denser medium is 1.5, **calculate** the absolute refractive index for the optically rarer medium. (1.15)

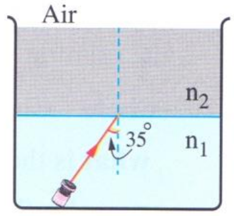
6. The frequency of a light wave is 5×10^{14} Hz. If its wavelength in the two media x and y are 5500 Å and 4000 Å respectively, **calculate :**
   (a) The velocity of that light in the two media.
   (b) The relative refractive index from x to y.
   (c) The relative refractive index from y to x.
   (d) The critical angle between the two media. (2.75×10^8 m/s , 2×10^8 m/s , 1.375 , 0.73 , 46.89°)

7. If the critical angle between glass and air is 42° and the critical angle between water and air is 48°. **Calculate :**
   (a) The relative refractive index from glass to water.
   (b) The critical angle between glass and water. (0.9, 64.16°)

8. **In the opposite figure :**
   A light ray falls on a semi-circular glass disc whose absolute refractive index is 1.5.
   Trace the path of the light ray if :
   (a) $\phi = 45°$ (b) $\phi = 60°$ (It reflects totally, 48.59°)



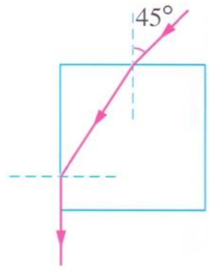
9. The opposite figure shows a light lamp which is placed at the bottom of a container under two layers of different liquids. The refractive index of the lower layer is 2 while the refractive index of the upper one is 1.5. A light ray falls from the lamp on the boundary between the two liquids at an angle of incidence 35°. **Trace the light ray and show if the ray will emerge to the air.**



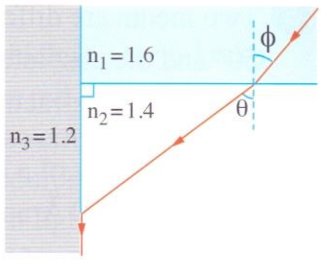
10 **Calculate** the radius of the smallest disc which is enough to block the light of a submerged lamp at a depth of 20 cm in a liquid of refractive index $\sqrt{2}$ where the disc floats on the surface of the liquid. If the depth of the lamp increased under the liquid surface, **will** the radius of the disc need to be changed ? (20 cm)

11 A light ray is falling on a square glass slab as in figure. **What** is the refractive index of the glass that makes the ray emerges tangent to the vertical face ?

(where : $\sin(90° - \theta) = \cos\theta$) (1.225)



12 The opposite figure shows a light ray that travels through medium 1 then falls on the boundary surface between the two media (1 , 2) where it enters medium 2 and falls on the boundary surface between the two media (2 , 3) at an angle that equals the critical angle for them :



(a) **Calculate** the value of angle ϕ.

(b) **Does** the ray pass into medium (3) if the value of the angle (ϕ) increases ? **Explain your answer.** (26.79°)

(Note that : $\sin(90° - \theta) = \cos\theta$)

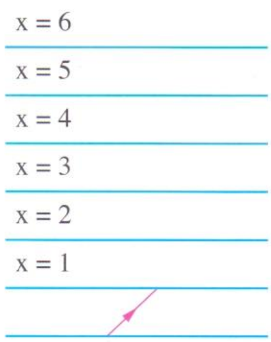
13 A light ray falls from glass on the boundary surface with air at an angle that equals the critical angle so it refracts tangentially to the glass surface. If a layer of water is placed on the glass surface, **calculate** the angle of refraction of the ray in air.

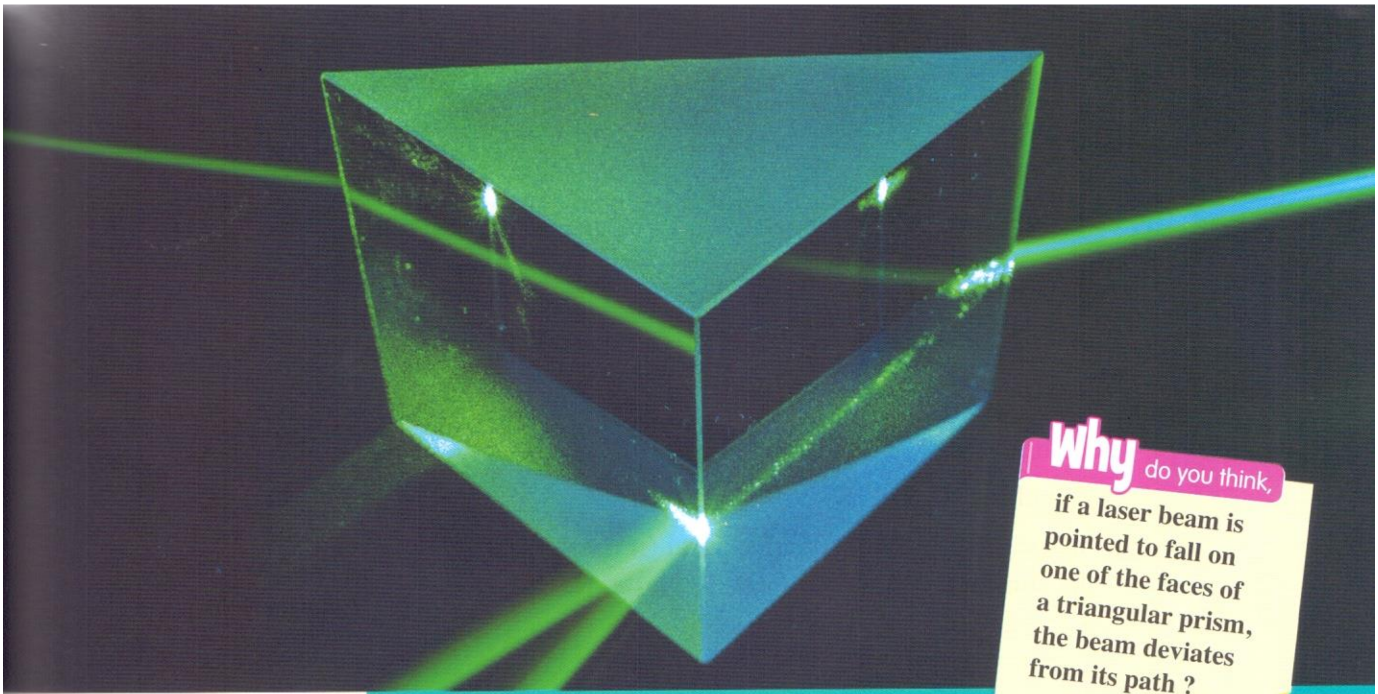
(where : the refractive index of glass = 1.5, the refractive index of water = $\frac{4}{3}$) (89.8°)

14 The opposite figure shows layers of different transparent materials which are placed above each other. If a light ray falls on them as in the opposite figure, the refractive index of the layer which contains the light source is n_o and the refractive index of each of the other layers is given by the relation : $n = n_o - \frac{n_o}{4x - 10}$

(where : x is the number of the layer)

, **what** is the layer that may encompass the total internal reflection of the light ray ? (2)



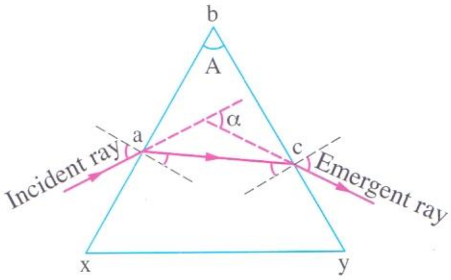


Why do you think, if a laser beam is pointed to fall on one of the faces of a triangular prism, the beam deviates from its path ?

Chapter 2

Lesson Four

Deviation of Light in a Triangular Prism



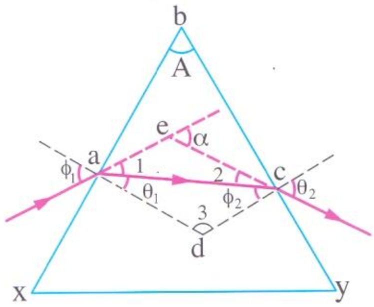
- If a light ray falls on face xb of the prism;

1. It refracts inside the prism taking the path ac.
2. Then it falls on face yb and emerges from the prism.

- The light ray refracts twice; the first at face xb and the second at face yb.

i.e. The light ray deviates from its path by a certain angle, which is called **angle of deviation (α)** which is the angle subtended by the extensions of the incident ray and the emerging ray in a triangular prism.

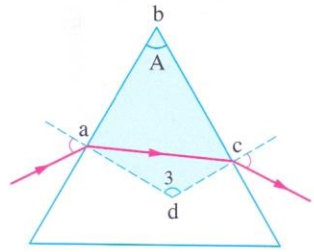
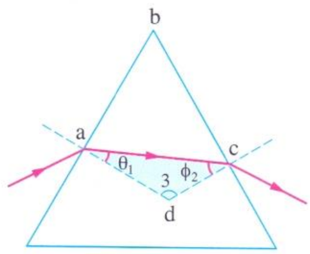
Deducing the laws of a triangular prism



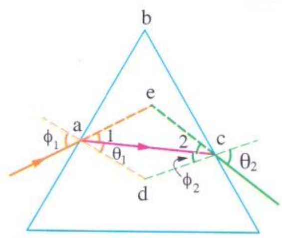
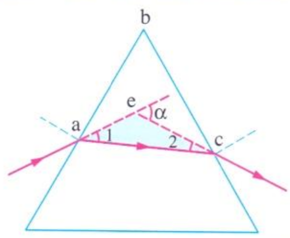
In the prism shown in the figure :

- A is the apex angle of the prism (the angle between the two faces of the prism where the light ray enters through one of them and emerges from the other one).
- ϕ_1 is the angle of incidence at the first surface (where light enters).
- θ_1 is the angle of refraction at the first face.
- ϕ_2 is the angle of incidence at the second surface (where light emerges).
- θ_2 is the angle of emergence.

First The apex angle of the prism (A) :

(1)	In the shape abcd : $\because$ $\overline{ad}$ is perpendicular to $\overline{ab}$ and $\overline{dc}$ is perpendicular to $\overline{cb}$ *i.e.* $\angle$ bad = 90° , $\angle$ bcd = 90° $\therefore$ $\angle$ bad + $\angle$ bcd = 180° $\therefore$ Shape abcd is cyclic quadrilateral (it means that the sum of each two opposite angles = 180°) $\therefore$ $A + \hat{3} = 180°$	
(2)	In the triangle acd : Sum of the angles = 180° $\therefore \theta_1 + \phi_2 + \hat{3} = 180°$	
(3)	From (1) , (2) : $\therefore$ $\boxed{A = \theta_1 + \phi_2}$	

Second The angle of deviation (α) :

(1)	$\because \phi_1 = \hat{1} + \theta_1$, $\theta_2 = \hat{2} + \phi_2$, because they are vertically opposite angles. $\therefore \hat{1} = \phi_1 - \theta_1$, $\hat{2} = \theta_2 - \phi_2$	
(2)	In the triangle aec : $\because$ The angle of deviation is an exterior angle of the triangle aec. $\therefore \alpha = \hat{1} + \hat{2}$	
(3)	From (1) , (2) : $\therefore \alpha = \phi_1 - \theta_1 + \theta_2 - \phi_2$ $= \phi_1 + \theta_2 - (\theta_1 + \phi_2)$ $\because A = \theta_1 + \phi_2$ $\therefore$ $\boxed{\alpha = \phi_1 + \theta_2 - A}$	

Third The refractive index of the material of the prism (n) :

$n_{air} \sin \phi_{air} = n_{glass} \sin \theta_{glass}$

$\because n_{air} = 1$

$\therefore n_{glass} = \dfrac{\sin \phi_{air}}{\sin \theta_{glass}}$

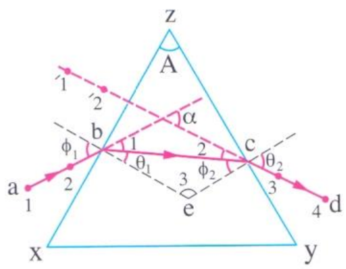
$$\therefore \quad \boxed{n = \frac{\sin \phi_1}{\sin \theta_1} = \frac{\sin \theta_2}{\sin \phi_2}}$$

Practical Experiment

Determining the refractive index of a triangular prism.

Objective :

- Tracing the path of a light ray through a triangular prism and deducing the laws of the prism.



Tools :

- An equilateral triangular prism (A = 60°).
- A protractor.
- A ruler.
- Pins.

Steps :

1. Place the glass prism on a drawing paper sheet in a vertical position and mark its position with a fine pencil line.
2. Place two pins such that one of them (2) is very close to one side and the other (1) is about 10 cm from the first. The line joining them represents the incident ray (line ab).
3. Look at the other side of the prism to see the image of the two pins, one behind the other.
4. Place two other pins (3) and (4) between the prism and the eye such that the four pins appear to be in one straight line.
5. Remove the prism and the pins and join b and c to locate the path of the ray (abcd) from air to glass to air again.
6. Extend cd to meet the extension of ab.The angle between them is the angle of deviation (α).
7. Measure : ϕ_1, θ_1, ϕ_2, θ_2 and α using the protractor.
8. Repeat the previous steps several times changing the angle of incidence (ϕ_1) and record the results in a table as the following :

Angle of incidence (ϕ_1)	Angle of refraction (θ_1)	2nd angle of incidence (ϕ_2)	Angle of emergence (θ_2)	Angle of deviation (α)	Apex angle (A)

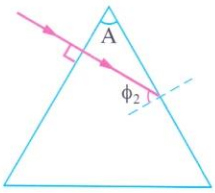
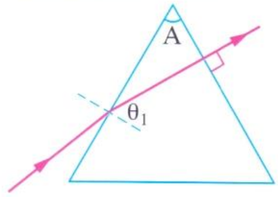
9. Verify the results with the relations :

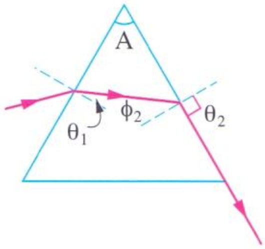
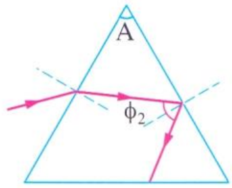
$A = \theta_1 + \phi_2 \quad , \quad \alpha = (\phi_1 + \theta_2) - A$

The factors that affect each of :

1 The angle of refraction (θ_1)	1. The refractive index of the prism for the used light (n). 2. The first angle of incidence (ϕ_1).
2 The second angle of incidence (ϕ_2)	1. The angle of refraction (θ_1). 2. The apex angle (A).
3 The angle of emergence (θ_2)	1. The refractive index of the prism for the used light (n). 2. The second angle of incidence (ϕ_2).
4 The angle of deviation (α)	1. The apex angle (A). 2. The first angle of incidence (ϕ_1). 3. The refractive index of the prism for the used light (n).
5 The apex angle (A)	- It is constant for the prism. - Doesn't depend on the angle of refraction (θ_1) nor the second angle of incidence (ϕ_2).

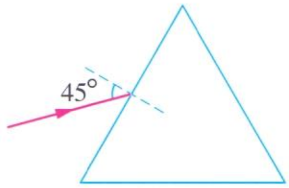
Special cases for the triangular prism

When the ray falls normally	When the ray emerges normally
 $\therefore \phi_1 = \theta_1 = 0°$ The ray enters through the first surface without any refraction $\therefore A = \phi_2$ $\alpha = \theta_2 - A$	 $\therefore \phi_2 = \theta_2 = 0°$ The ray emerges through the second surface without any refraction $\therefore A = \theta_1$ $\therefore \alpha = \phi_1 - A$

When the ray emerges tangentially	When the ray reflects totally inside the prism
 $\therefore \phi_2 = \phi_c$, $\theta_2 = 90°$ $\therefore n = \frac{1}{\sin \phi_c}$ $A = \theta_1 + \phi_c$	 $\phi_2 > \phi_c$ The ray encounters total internal reflection, where : ϕ_2 = The angle of reflection

Example 1

The opposite figure shows an equilateral triangular prism whose refractive index equals 1.5. If a light ray falls on one of its faces at an angle 45°, calculate :



(a) The angle of emergence of the ray.

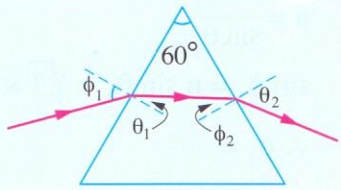
(b) The angle of deviation.

Solution

$\phi_1 = 45°$ $n = 1.5$ $A = 60°$

Clue

(a) *To find the angle of emergence* (θ_2) *we must calculate* θ_1 , ϕ_2.



$n = \frac{\sin \phi_1}{\sin \theta_1}$ $\therefore \sin \theta_1 = \frac{\sin 45}{1.5}$ $\therefore \theta_1 = 28.13°$

$A = \theta_1 + \phi_2$

$\therefore \phi_2 = A - \theta_1 = 60 - 28.13 = 31.87°$

$n = \frac{\sin \theta_2}{\sin \phi_2}$ $\sin \theta_2 = n \sin \phi_2 = 1.5 \sin 31.87°$

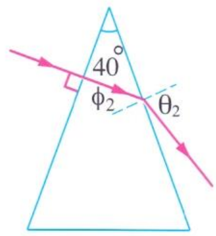
$\therefore \theta_2 = 52.37°$

(b) $\alpha = \phi_1 + \theta_2 - A$

$= 45 + 52.37 - 60 = 37.37°$

Example 2

The opposite figure shows a light ray which falls normally on one of the faces of a triangular prism of an apex angle 40°, if $\theta_2 = 1.5\ \phi_2$, calculate the refractive index of the prism.



Solution

$A = 40°$ | $\theta_2 = 1.5\ \phi_2$ | $\theta_1 = \phi_1 = 0°$

$\because A = \theta_1 + \phi_2$

$\therefore \phi_2 = A = 40°$ $\qquad$ $\therefore \theta_2 = 1.5 \times 40 = 60°$

$$n = \frac{\sin \theta_2}{\sin \phi_2} = \frac{\sin 60}{\sin 40} = 1.35$$

Example 3

A light ray falls on the face of a triangular prism whose refractive index is $\sqrt{3}$ and apex angle equals 30°. If the ray emerges normally from the other side, calculate the angle of incidence.

Solution

$A = 30°$ | $n = \sqrt{3}$ | $\phi_2 = \theta_2 = 0°$

$A = \theta_1 + \phi_2$, $\quad 30 = \theta_1 + 0$, $\quad \theta_1 = 30°$

$$n = \frac{\sin \phi_1}{\sin \theta_1}$$

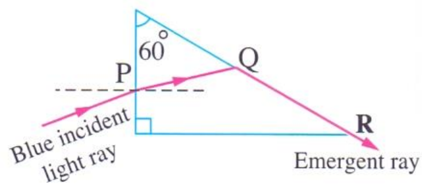
$\sin \phi_1 = n \sin \theta_1 = \sqrt{3} \times \sin 30$

$\therefore \phi_1 = 60°$

Example 4

In the opposite figure :

If a blue light ray falls on the face of a prism at point P and the angle of refraction equals 23° then it falls on the other side at point Q and emerges tangent to the surface QR. Find :



(a) The critical angle of blue light.

(b) The refractive index of the prism material for the blue light.

Solution

$\theta_1 = 23^\circ$ | $A = 60^\circ$ | $\theta_2 = 90^\circ$

(a) $A = \theta_1 + \phi_2$, $60 = 23 + \phi_2$, $\therefore \phi_2 = 37^\circ$ $\phi_c = \phi_2 = 37^\circ$

(b) $n = \dfrac{1}{\sin \phi_c} = \dfrac{1}{\sin 37} = 1.66$

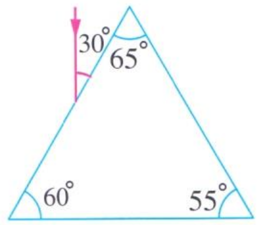
Example 5

In the opposite figure, if the refractive index of the prism's material is 1.5 :

(a) Trace the light ray.

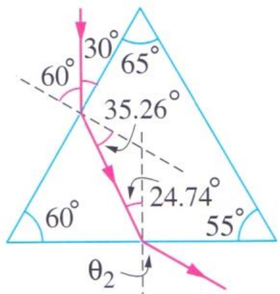
(b) Find the angle of emergence from the prism.

(c) Find the angle of deviation.



Solution

$A = 60^\circ$ | $n = 1.5$



(a) $n = \dfrac{\sin \phi_1}{\sin \theta_1}$

$\sin \theta_1 = \dfrac{\sin \phi_1}{n} = \dfrac{\sin 60}{1.5}$

$\theta_1 = 35.26^\circ$, $A = \theta_1 + \phi_2$

$60 = 35.26 + \phi_2$, $\phi_2 = 24.74^\circ$

$\sin \phi_c = \dfrac{1}{n} = \dfrac{1}{1.5}$, $\phi_c = 41.81^\circ$

$\because \phi_2 < \phi_c$

$\therefore$ The light refracts outside the prism approaching the separating surface.

(b) $n = \dfrac{\sin \theta_2}{\sin \phi_2}$

$\sin \theta_2 = n \sin \phi_2 = 1.5 \times \sin 24.74$ $\theta_2 = 38.88^\circ$

(c) $\alpha = (\phi_1 + \theta_2) - A$

$= 60 + 38.88 - 60 = 38.88^\circ$

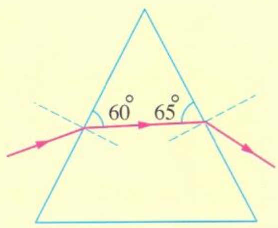
7 Test yourself

In the opposite figure if the refractive index of the prism is 1.5, **calculate** the angle of deviation of the light ray.

....

....

....



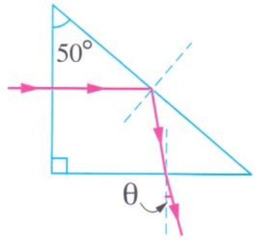
QUESTIONS ON
Chapter 2
LESSON FOUR
Deviation of Light in a Triangular Prism

Interactive test

First Multiple choice questions

1 In the opposite figure :

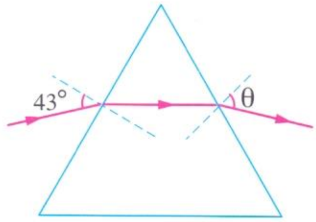
If the refractive index of the prism material is 1.5, then the value of angle θ almost equals ....



(a) 80° (b) 50°

(c) 15° (d) 10°

2 The opposite figure shows the path of a light ray through an equilateral triangular prism of refractive index 1.5, so angle θ equals ....

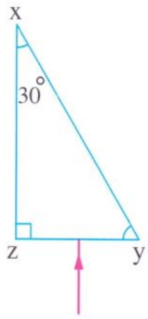


(a) 47.2° (b) 43°

(c) 54.7° (d) 27°

3 In the opposite figure :

A ray falls perpendicularly on face yz. If the critical angle of glass is 42°, which statement of the following is correct ? ....



(a) The ray passes through face yz without deviation

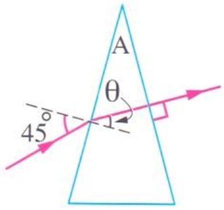
(b) The angle of incidence of the ray on face xy equals 60°

(c) The ray reflects totally on face xy

(d) All the previous

4 In the opposite figure :

The apex angle (A) of the prism is ....



(a) more than 45° (b) less than 45°

(c) equal to 45° (d) indeterminable

5 A light ray falls normally on one of the faces of a triangular prism of apex angle 30°. If the refractive index of the prism is $\sqrt{2}$;

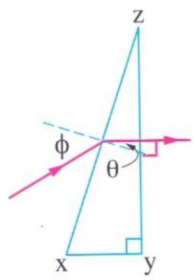
(i) the angle of emergence from the prism equals ....

(a) 15° (b) 30° (c) 45° (d) 60°

(ii) the angle of deviation of the ray equals ....

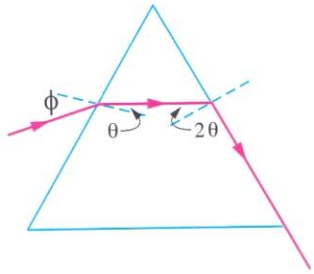
(a) 15° (b) 30° (c) 45° (d) 60°

6 In the opposite figure, if $\ell_{xz} = 3\ \ell_{xy}$ and the angle of deviation is 30°, so .... , ...



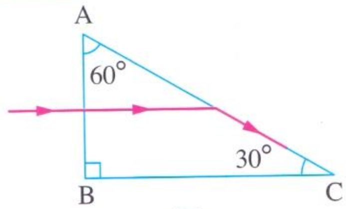
	ϕ	θ
a	48.43°	71.57°
b	41.57°	71.57°
c	49.47°	19.47°
d	41.57°	18.43°

7 The opposite figure shows a light ray falling on an equilateral triangular prism. If the ray emerges tangentially from one of the faces of the prism, the angle of incidence (ϕ) equals ....



a) 45.52°
b) 36.24°
c) 32.25°
d) 27.22°

8 The opposite figure shows a prism of refractive index 1.5 and the prism is submerged in a liquid of refractive index n. If a light ray falls perpendicularly on the face AB and the ray emerges tangentially to face AC, so n = ...

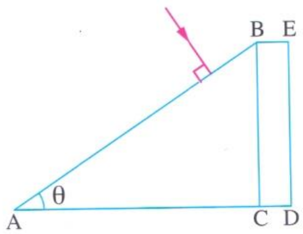


a) $\frac{2\sqrt{3}}{3}$
b) $\frac{5}{3}$
c) $\frac{4}{3}$
d) $\frac{3\sqrt{3}}{4}$

9 A triangular prism has an apex angle 60° and refractive index $\sqrt{3}$, so the minimum angle of incidence of a ray on one of the faces of the prism that makes the ray emerge from the other face of the prism is ....

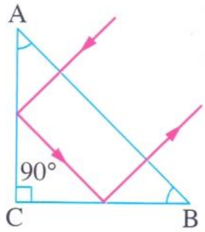
a) 32.32°
b) 37.37°
c) 42.42°
d) 46.46°

10 The opposite figure shows a light ray falling on a right triangular prism ABC which is made of a material of refractive index 1.5 where a glass slab BCDE of refractive index 1.2 is placed on face BC.
If the ray doesn't traverse face BC, the angle θ is ....



a) less than 36.87°
b) greater than 36.87°
c) less than 53.13°
d) greater than 53.13°

11. A ray of light is incident normally on an isosceles right angled prism as shown in the figure. The least value of the refractive index of the prism must be ....

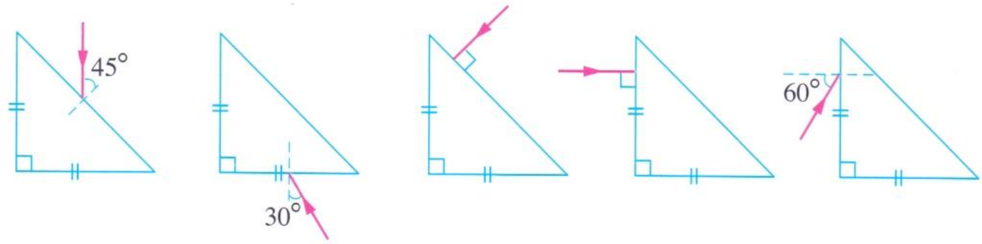


(a) $\sqrt{2}$
(b) $\sqrt{3}$
(c) 1.5
(d) 2

Second Essay questions

1. **What** are the factors on which the angle of deviation in the triangular prism depend ?

2. The following figures shows five different cases of the falling of a light ray on a triangular prism of refractive index 1.5 :



In which of these figures the following actions happen ? (Provide your answers with drawings) :

(a) the ray deviates with an angle 90°

(b) the ray emerges from the same face of its incidence.

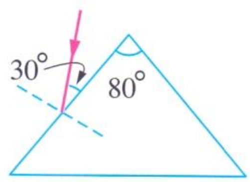
(c) the ray suffers total internal reflections twice inside the prism.

Third Problems

1. A ray of light falls on a triangular glass prism at an angle of incidence of 45° then it emerges by an angle of 52°. If you know that the refractive index of the prism material is 1.5, **calculate** the apex angle of the prism. (59.82°)

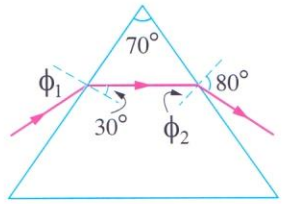
2. A light ray falls at an angle 60° on one face of an equilateral triangular prism whose refractive index is $\sqrt{3}$. **Find** the angles of emergence and deviation of the light ray. (60° , 60°)

3. The opposite figure shows an isosceles triangular prism which is made of a material of refractive index 1.5 and a light ray falls on one of its faces :



(a) **Trace** the path of the ray.
(b) **Calculate** the angle of deviation of the ray. (32.44°)

4 **For the opposite figure, calculate each of the following :**



(a) The second angle of incidence (ϕ_2).

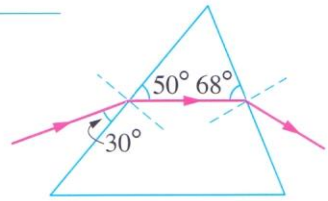
(b) The refractive index of the prism (n).

(c) The first angle of incidence (ϕ_1).

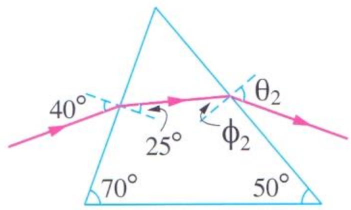
(d) The angle of deviation (α).

(40° , 1.53 , 49.91° , 59.91°)

5 The opposite figure shows the path of a light ray falling on a triangular prism. **Calculate** the angle of deviation. (28.38°)



6 **For the opposite figure, calculate each of the following :**



(a) The apex angle of the prism (A).

(b) The second angle of incidence (ϕ_2).

(c) The refractive index of the prism (n).

(d) The angle of emergence (θ_2).

(60° , 35° , 1.52 , 60.67°)

7 The apex angle of a triangular prism is 45°, if a ray of light falls perpendicularly on one of its faces then it emerges as a tangent to the other face. **Calculate** the refractive index of the prism material. ($\sqrt{2}$)

8 A light ray fell perpendicularly on one of the faces of a triangular prism whose refractive index is $\sqrt{2}$. If the ray emerged tangentially to the other face of the prism, **find** the apex angle of the prism. (45°)

9 A ray of light falls from air on the face of a triangular glass prism whose apex angle is 72°. If the ray is refracted by an angle of 30° and emerged tangentially to the other face, **find :**

(a) The critical angle between glass and air.

(b) The refractive index of the prism material.

(c) The sine of the first angle of incidence.

(42° , 1.49 , 0.745)

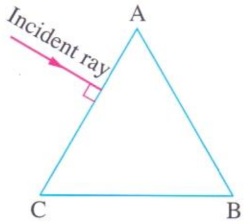
10 The apex angle of a triangular prism is 70° and its refractive index is 1.58. **Calculate** the angle of incidence of a light ray which is incident on one of the faces of the prism if you know that the light ray emerged tangentially to the other face. (53.8°)

11 A light ray fell on one of the faces of a triangular prism whose apex angle is 30° then the ray emerges perpendicularly on the other face. If the refractive index of the prism is $\sqrt{3}$, **calculate** the angle of incidence of the light ray. (60°)

12. The apex angle of a triangular prism is 30°, a light ray falls perpendicularly on one of its faces, then it deviated by an angle that equals 20°. **Find** the refractive index of the prism material. (1.532)

13. A light ray falls at an angle 60° on one of the faces of a triangular prism whose apex angle is 40° then the ray emerges perpendicularly from the other face, **calculate** the refractive index of the prism. (1.35)

14. **The opposite figure** shows an equilateral triangular prism made of glass whose refractive index is 1.5. If a light ray is incident perpendicularly to the face AC :



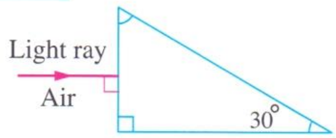
(a) **Trace** the path of the light ray till it emerges.

(b) **Find :**

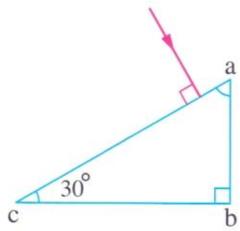
1- The angle of emergence of the light ray.

2- The angle between the extensions of the incident ray and the emergent ray. (0 , 60°)

15. **Trace** the path of the incident light ray on one of the faces of a glass prism (as shown in the figure) until it emerges knowing that the refractive index of the prism is 1.5. **Then find** the value of the emergence angle of this ray. (48.59°)



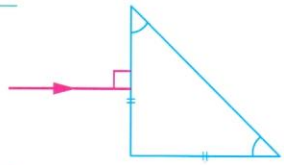
16. Light ray is incident perpendicular to one face of a triangular prism of refractive index 1.5 as shown in the figure :



(a) **Trace** the path of the light ray inside the prism.

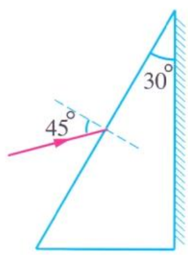
(b) **Find** its angle of emergence. (48.59°)

17. **Trace** the path of the light ray through the triangular prism, **then calculate** the angle of emergence knowing that the light ray falls from air ($n_{air} = 1$) to the glass ($n_{glass} = \sqrt{2}$). (90°)



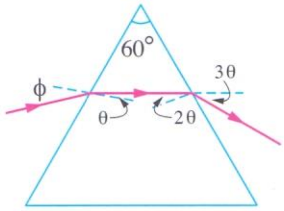
18. A light ray falls on one of the faces of a triangular prism whose apex angle equals 35°. If the ray deviates from its direction with an angle of 25° and emerges normally from the other face of the prism, **calculate** the refractive index of the prism. (1.51)

19. A triangular glass prism, one of its faces is silvered, has an apex angle of 30°. If a light ray falls at an angle of 45° on the face that opposes the silvered face, the ray refracts inside the prism then it reflects on the silvered face and retracts its path. **Trace** the path of the ray then **calculate** the refractive index of the prism. ($\sqrt{2}$)

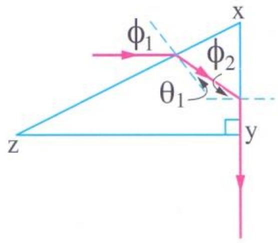


20 **From the opposite figure, calculate angle ϕ.**

(27.5°)

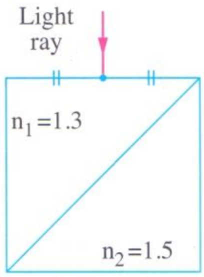


21 The opposite figure shows the path of a light ray which falls on face xz of a right triangular prism.
If $\ell_{xy} = \frac{1}{2}\ell_{yz}$, $\theta_1 = \frac{1}{2}\phi_2$, **calculate :**
(a) The refractive index of the prism.
(b) The angle of deviation. (1.49, 59.08°)

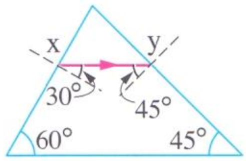


22 A triangular glass prism has an apex angle 75° and a refractive index $\sqrt{2}$. **Calculate** the minimum angle of incidence for a light ray to fall on one face and emerges from the other. (45°)

23 **In the opposite figure :**
A cube is formed of two different kinds of glass, **follow** the path of the falling light ray until it emerges **and find** the angle of emergence. (10.85°)

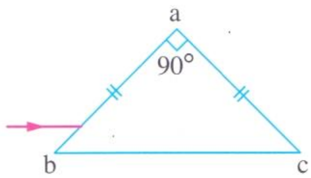


24 **In the opposite figure :**
If the critical angle of the prism's material is 42° , **draw** the path of the rays from the incidence to the emergence and **calculate** the values of the first angle of incidence and the angle of emergence.



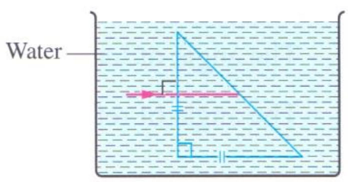
(48.16° , 0°)

25 **Follow** the path of the incident light ray on the face of a glass prism parallel to the base bc as in figure until it emerges, **then find** the angle of emergence.
(where : the refractive index of glass = 1.5)



(45°)

26 **In the opposite figure :**
Follow the path of the incident light ray till it emerges from the prism, where the critical angle for the prism's material in air is 42° and the absolute refractive index of water is 1.33.

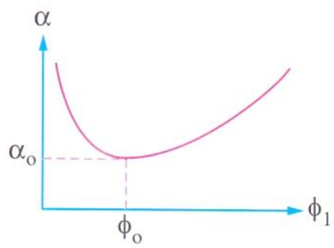


Chapter 2
Lesson Five
Minimum Deviation and Thin Prism

The minimum angle of deviation in the triangular prism

⊙ According to the relation : $\alpha = (\phi_1 + \theta_2) - A$

The angle of deviation in a prism of apex angle A depends on the angle of incidence ϕ_1 only. So when drawing the graphical relation between the angle of deviation (α) and the first angle of incidence (ϕ_1) as in the figure, **we find :**



- At first the angle of deviation decreases as the first angle of incidence (ϕ_1) increases until it reaches its minimum value (α_o) and then it increases again by increasing ϕ_1

⊙ α_o is called **the minimum angle of deviation**.

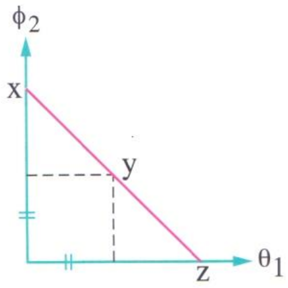
From the previous we can conclude that :

- The minimum deviation is the position where the angle of deviation has the smallest value.

At the minimum deviation we find :

- The angle of incidence (ϕ_1) = The angle of emergence (θ_2) = ϕ_o
- The angle of refraction (θ_1) = The second angle of incidence (ϕ_2) = θ_o

The relation between θ_1 and ϕ_2 in a triangular prism :



- The angle of refraction (θ_1) and the second angle of incidence (ϕ_2) are related by the relation :

  $A = \theta_1 + \phi_2$

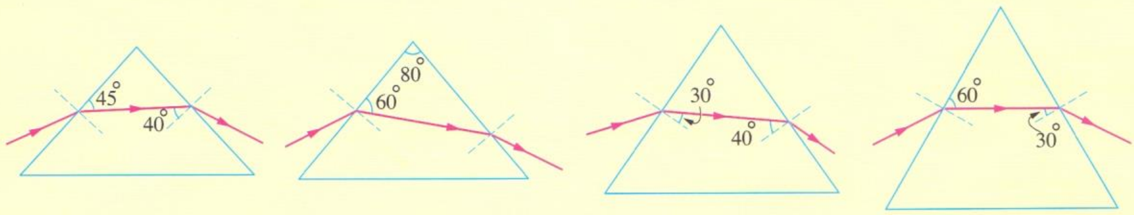
  $\therefore \phi_2 = A - \theta_1$

  The apex angle (A) is constant for the prism, so as θ_1 increases, ϕ_2 decreases and the relation between them can be represented as the opposite graph, where :

  - The points x and z represent the apex angle of the prism.
  - The point y represents the position of minimum deviation at which $\theta_1 = \phi_2$

8 Test yourself

Choose : In which of the following cases the prism is in the minimum deviation ? ....



(a) (b) (c) (d)

Deducing the prism's refractive index at the minimum deviation :

- When the prism is in the position of minimum deviation : $n = \dfrac{\sin \phi_o}{\sin \theta_o}$

To find

θ_o	ϕ_o
$\because \theta_1 = \phi_2 = \theta_o$	$\because \phi_1 = \theta_2 = \phi_o$
$A = \theta_1 + \phi_2$	$\alpha = \phi_1 + \theta_2 - A$
$\therefore A = 2\,\theta_o$	$\therefore \alpha_o = 2\,\phi_o - A$
$\therefore \theta_o = \frac{A}{2}$	$\therefore \phi_o = \frac{\alpha_o + A}{2}$

$$\therefore \quad \boxed{n = \frac{\sin\left(\frac{\alpha_o + A}{2}\right)}{\sin\left(\frac{A}{2}\right)}}$$

From the previous relation, we notice that :

$\because$ The apex angle of the prism is constant.

$\therefore$ Accordingly, as the refractive index of the prism differs for each color, the minimum angle of deviation also differs for each color.

i.e. When n increases, α_o increases also and vice versa.

$\because$ The refractive index (n) depends on the wavelength where : $n \propto \frac{1}{\lambda}$.

$\therefore$ α_o depends on the wavelength.

The factors affecting the minimum angle of deviation in a triangular prism :

1. The apex angle (A).
2. The refractive index of the prism (n).
3. The wavelength of the incident ray (λ).

Example 1

A triangular prism is made of a meterial whose refractive index is $\sqrt{2}$ where the angle of the prism equals 60°, calculate :

(a) The minimum angle of deviation.

(b) The angle of incidence and the angle of emergence at minimum deviation.

Solution

$n = \sqrt{2}$ $\quad$ $A = 60^\circ$

(a) $n = \dfrac{\sin\left(\frac{\alpha_o + A}{2}\right)}{\sin\left(\frac{A}{2}\right)}$, $\quad \sqrt{2} = \dfrac{\sin\left(\frac{\alpha_o + 60}{2}\right)}{\sin\left(\frac{60}{2}\right)}$

$\frac{\alpha_o + 60}{2} = 45^\circ$, $\quad \alpha_o = 30^\circ$

(b) $\phi_1 = \theta_2 = \frac{\alpha_o + A}{2} = \frac{30 + 60}{2} = 45^\circ$

Example 2

A triangular prism whose apex angle is 60°. If the first angle of incidence equals double the angle of refraction at the minimum deviation, calculate the minimum angle of deviation.

Solution

$\boxed{A = 60°}$ $\boxed{\phi_1 = 2\theta_1}$

$\theta_1 = \frac{A}{2} = \frac{60}{2} = 30°$

$\phi_1 = 2\theta_1 = 2 \times 30 = 60°$

$\alpha_o = 2\phi_1 - A$

$= (2 \times 60) - 60 = 60°$

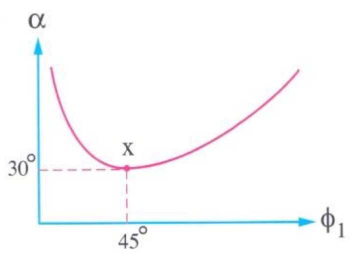
Example 3

The opposite figure represents the graphical relation between the first angle of incidence (ϕ_1) and the angle of deviation (α) in a triangular prism, calculate :

(a) The apex angle of the prism.

(b) The refractive index of the prism.

(c) The angle of emergence from the prism.



Solution

(a) At point x the prism is at minimum deviation :

$\alpha_o = 2\phi_o - A$, $30 = (2 \times 45) - A$

$\therefore A = 60°$

(b) $n = \dfrac{\sin\left(\frac{\alpha_o + A}{2}\right)}{\sin\left(\frac{A}{2}\right)} = \dfrac{\sin\left(\frac{30+60}{2}\right)}{\sin\left(\frac{60}{2}\right)} = \sqrt{2}$

Another solution :

$\theta_o = \frac{A}{2} = \frac{60}{2} = 30°$, $n = \dfrac{\sin\phi_o}{\sin\theta_o} = \dfrac{\sin 45}{\sin 30} = \sqrt{2}$

(c) $\theta_2 = \phi_1 = 45°$

Example 4

A triangular prism becomes at minimum deviation when a light ray falls on one of its faces at an angle of incidence 50°. If the angle of the prism equals 1.5 α_o, calculate the refractive index of the prism.

Solution

$\phi_o = 50°$ $A = 1.5\ \alpha_o$

$\alpha_o = 2\ \phi_o - A$

$\alpha_o = (2 \times 50) - 1.5\ \alpha_o$

$\therefore \alpha_o = 40°$

$A = 1.5\ \alpha_o = 1.5 \times 40 = 60°$

$$n = \frac{\sin\left(\frac{\alpha_o + A}{2}\right)}{\sin\left(\frac{A}{2}\right)} = \frac{\sin\left(\frac{40 + 60}{2}\right)}{\sin\left(\frac{60}{2}\right)} = 1.53$$

9 *Test yourself*

The opposite graph depicts the relation between the angle of refraction (θ_1) and the angle of incidence (ϕ_2) in a triangular prism of refractive index 1.5.

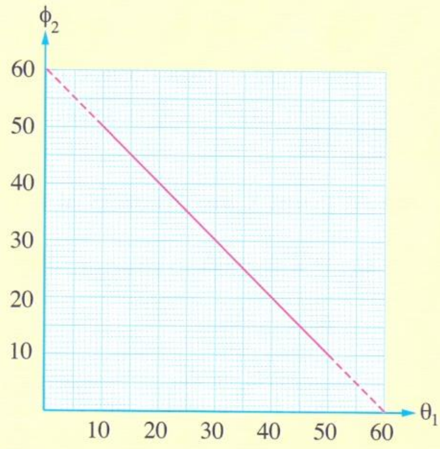
Calculate the angle of minimum deviation.

....

....

....

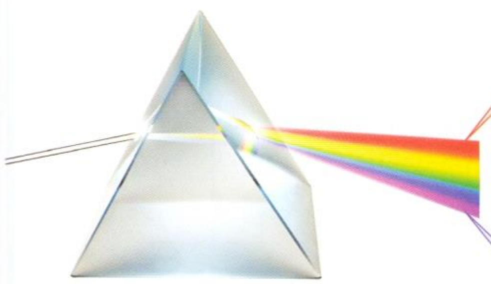
....



Dispersion of light by the triangular prism

White light consists of seven colors each color has a certain wavelength, hence each color has a different angle of deviation, so if white light fell on a triangular prism at minimum deviation, it emerges from the prism separated into seven colors of the spectrum of white light which can be listed as their order from the apex to the base of the prism as the following :

Red → **Orange** → **Yellow** → **Green** → **Blue** → **Indigo** → **Violet**

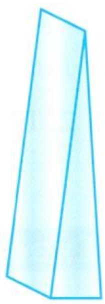


Red light has the least angle of deviation because it has the largest wavelength and as ($n \propto \frac{1}{\lambda}$) so the refractive index of red light has the least value and the smallest deviation.

Violet light has the largest angle of deviation because it has the smallest wavelength and hence it has the largest refractive index and the largest deviation.

- The dispersion of light happens distinctly when the prism is set in minimum deviation position.

Thin prism



- It is a triangular prism made of a transparent material (glass) of very small apex angle that does not exceed 10° and always set at the position of minimum deviation.
- There are some concepts related to the thin prism :

Concepts related to the thin prism

1. Deviation angle
2. Angular dispersion
3. Dispersive power

1 Deviation angle

Deducing the deviation angle of the thin prism :

$\because$ The thin prism is always in the position of minimum deviation.

$\therefore$ The refractive index of the prism's material can be estimated from the relation :

$$n = \frac{\sin\left(\frac{\alpha_o + A}{2}\right)}{\sin\left(\frac{A}{2}\right)}$$

$\because \frac{\alpha_o + A}{2}, \frac{A}{2}$ are small angles, then the sine of these angles equal to their angles in radian.

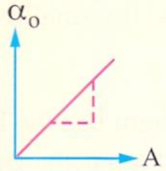
$$\therefore n = \frac{\frac{\alpha_o + A}{2}}{\frac{A}{2}} = \frac{\alpha_o + A}{A}$$

$\therefore \alpha_o + A = An$ $\qquad \therefore \boxed{\alpha_o = A(n-1)}$

The factors affecting the angle of deviation in the thin prism :

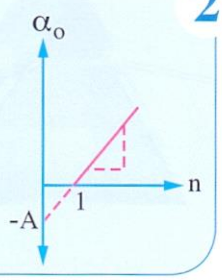
1 The apex angle of the thin prism "directly proportional"

Slope = $\frac{\Delta \alpha_o}{\Delta A} = n - 1$



2 The refractive index of its material "directly proportional"

Slope = $\frac{\Delta \alpha_o}{\Delta n} = A$



$$\alpha_o = A\,(n - 1)$$

Notes :

1. α_o in the thin prism doesn't depend on the first angle of incidence which doesn't exceed 10°.
2. The angle of deviation in the thin prism depends on the wavelength of the incident light (λ).

Example 1

A thin prism has an apex angle of 7° and refractive index 1.5. Calculate the angle of deviation.

Solution

$A = 7^\circ$ $\quad$ $n = 1.5$

$\alpha_o = A\,(n - 1)$

$= 7 \times (1.5 - 1) = 3.5^\circ$

Example 2

When a light ray fell on a thin prism of apex angle A and refractive index n, the ray deviated by an angle of 4°. If the prism is submerged in a liquid of refractive index 1.2, the angle of deviation becomes 2°.

Calculate :

(a) The refractive index of the prism.

(b) The apex angle of the prism.

Solution

$(\alpha_o)_1 = 4^\circ$ | $n_{liquid} = 1.2$ | $(\alpha_o)_2 = 2^\circ$

(a) **Clue**

When putting a prism of refractive index n_1 in a liquid of refractive index n_2 :

$$\alpha_o = A\left(\frac{n_1}{n_2} - 1\right)$$

- Before submerging the prism in the liquid :

$(\alpha_o)_1 = A\,(n - 1)$

$4 \quad = A\,(n - 1)$ (1)

- After submerging the prism in the liquid :

$(\alpha_o)_2 = A\left(\frac{n}{n_{liquid}} - 1\right)$

$2 = A\left(\frac{n}{1.2} - 1\right)$ (2)

By dividing equation (1) by equation (2) :

$$\frac{4}{2} = \frac{A\,(n-1)}{A\left(\frac{n}{1.2} - 1\right)}$$

$2\left(\frac{n}{1.2} - 1\right) = n - 1$

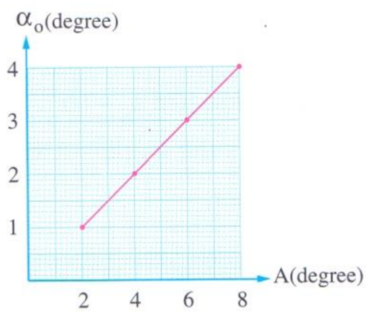
$\frac{2\,n}{1.2} - 2 = n - 1$ $\qquad \therefore n = 1.5$

(b) By substituting with n in equation (1) :

$4 = A\,(1.5 - 1)$ $\qquad \therefore A = 8^\circ$

Example 3

The opposite graph depicts the relation between the apex angles of multiple thin prisms which are made of the same type of glass and the deviation of a light ray in these prisms, calculate the refractive index of the glass of which the prisms are made.



Solution

$$\text{Slope} = \frac{\Delta\alpha_o}{\Delta A} = \frac{4-2}{8-4} = 0.5$$

Slope = n – 1 = 0.5

$\therefore n = 1.5$

10 Test yourself

Choose : A laser beam falls on a thin prism at an angle of incidence (ϕ_1), then the largest angle of deviation appears when ....

(a) $\phi_1 = 4°$ (b) $\phi_1 = 5°$ (c) $\phi_1 = 6°$ (d) All of them have the same deviation angle

2 Angular dispersion

Deduction of angular dispersion in thin prism :

$\because$ The thin prism is always in the position of minimum deviation and the angle of deviation depends on the refractive index of the thin prism for the falling light ray which in turn depends on the wavelength of the falling light ray.

$\therefore$ The angle of deviation of the light ray changes by changing the wavelength of the ray, so the thin prism disperses the white light into the seven spectral colors, where :

- The angle of deviation of the red light is estimated from the relation :

$$(\alpha_o)_r = A\,(n_r - 1)$$

- The angle of deviation of the blue light is estimated from the relation :

$$(\alpha_o)_b = A\,(n_b - 1)$$

Where : (n_r) is the prism's refractive index for red light and (n_b) is the prism's refractive index for blue light.

$$\because n_b > n_r \qquad \therefore (\alpha_o)_b > (\alpha_o)_r$$

By subtracting the two previous equations : $(\alpha_o)_b - (\alpha_o)_r = A\,(n_b - 1) - A\,(n_r - 1)$

$$\therefore \boxed{(\alpha_o)_b - (\alpha_o)_r = A\,(n_b - n_r)}$$

⊙ The value $[(\alpha_o)_b - (\alpha_o)_r]$ is called **the angular dispersion** between the blue and the red rays which is the angle between the extensions of the two colors after their emergence from the prism.

The factors affecting the angular dispersion :

1. The apex angle of the prism.
2. The prism's refractive index for both blue and red colors.

The yellow color is considered the middle between the blue and red color, so we can define :

The average refractive index (n_y) :

It is the refractive index of yellow light (n_y).

The average deviation $(\alpha_o)_y$:

It is the deviation of yellow light $(\alpha_o)_y$

From the relation

$$n_y = \frac{n_b + n_r}{2}$$

$$(\alpha_o)_y = \frac{(\alpha_o)_b + (\alpha_o)_r}{2}$$

3 Dispersive power

- **The dispersive power (ω_α)** is the ratio of the angular dispersion for blue and red color to the angle of deviation for the yellow color (the middle angle of deviation).

Deduction of dispersive power :

$\because (\alpha_o)_r = A(n_r - 1) \quad , \quad (\alpha_o)_b = A(n_b - 1)$

$\therefore (\alpha_o)_b - (\alpha_o)_r = A(n_b - n_r)$

The angle of deviation for the yellow light (middle between the blue and the red) is :

$(\alpha_o)_y = A(n_y - 1)$

Where : (n_y) is the refractive index for yellow.

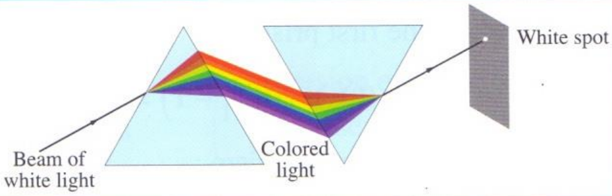
$$\therefore \omega_\alpha = \frac{(\alpha_o)_b - (\alpha_o)_r}{(\alpha_o)_y} = \frac{A(n_b - n_r)}{A(n_y - 1)} \qquad \therefore \boxed{\omega_\alpha = \frac{n_b - n_r}{n_y - 1}}$$

The factors affecting the dispersive power of a thin prism :

The prism's refractive index for the blue, red and yellow colors.

Note :

- The rectangular glass does not disperse light because it acts as two similar reversed prisms; one cancels the dispersion of the other.



Example 1

A thin prism has an apex angle of 8°, its refractive index for red color is 1.52 and its refractive index for blue color is 1.54 . Calculate :

(a) The angle of deviation for each color.

(b) The angular dispersion between the two colors.

(c) The dispersive power of the prism.

Solution

$A = 8^\circ$ $n_r = 1.52$ $n_b = 1.54$

(a) $(\alpha_o)_b = A\,(n_b - 1) = 8 \times (1.54 - 1) = 4.32^\circ$

$(\alpha_o)_r = A\,(n_r - 1) = 8 \times (1.52 - 1) = 4.16^\circ$

(b) $(\alpha_o)_b - (\alpha_o)_r = 4.32 - 4.16 = 0.16^\circ$

Another Solution

$(\alpha_o)_b - (\alpha_o)_r = A\,(n_b - n_r) = 8 \times (1.54 - 1.52) = 0.16^\circ$

(c) $n_y = \dfrac{n_b + n_r}{2} = \dfrac{1.54 + 1.52}{2} = 1.53$

$\omega_\alpha = \dfrac{n_b - n_r}{n_y - 1} = \dfrac{1.54 - 1.52}{1.53 - 1} = 0.038$

Example 2

We have two thin prisms, the first prism is made of rock glass of average refractive index 1.6 and dispersive power 0.036, while the second prism is made of crown glass of average refractive index 1.5 and dispersive power 0.028. If the apex angle of the second prism is 7°, calculate the apex angle of the first prism, knowing that the two prisms have the same angular dispersion.

Solution

$(n_y)_1 = 1.6$ $(\omega_\alpha)_1 = 0.036$ $(n_y)_2 = 1.5$ $(\omega_\alpha)_2 = 0.028$ $A_2 = 7^\circ$

$\because \omega_\alpha = \dfrac{n_b - n_r}{n_y - 1}$ $\therefore n_b - n_r = \omega_\alpha\,(n_y - 1)$

- In case of the first prism :

$(n_b)_1 - (n_r)_1 = (\omega_\alpha)_1\big((n_y)_1 - 1\big) = 0.036 \times (1.6 - 1) = 0.0216$

- In case of the second prism :

$(n_b)_2 - (n_r)_2 = (\omega_\alpha)_2\big((n_y)_2 - 1\big) = 0.028 \times (1.5 - 1) = 0.014$

$\because$ They have the same angular dispersion :

$\therefore A_1\big((n_b)_1 - (n_r)_1\big) = A_2\big((n_b)_2 - (n_r)_2\big)$

$\therefore A_1 \times 0.0216 = 7 \times 0.014$ $\therefore A_1 = \dfrac{7 \times 0.014}{0.0216} = 4.54^\circ$

11 Test yourself

A thin prism has an apex angle of 10°, refractive index for red light 1.52 and for blue light 1.58. **Calculate** the angular dispersion and the dispersive power for the prism.

....

....

....

➲ From the previous we can compare between the normal prism and the thin prism as follows :

Points of Comparison	The normal prism	The thin prism
The apex angle of the prism (A) :	Large (more than 10°)	Small (less than 10°)
The refractive index (n) :	$n = \frac{\sin \phi_1}{\sin \theta_1} = \frac{\sin \theta_2}{\sin \phi_2}$	$n = \frac{\alpha_o + A}{A}$
The angle of deviation :	$\alpha = \phi_1 + \theta_2 - A$	$\alpha_o = A(n - 1)$ Always at the minimum deviation angle
The position of minimum deviation :	Not always in the position of minimum deviation and its refractive index is given by : $n = \frac{\sin\left(\frac{\alpha_o + A}{2}\right)}{\sin\left(\frac{A}{2}\right)}$	Always in the position of minimum deviation.
Uses :	- Spectral dispersion. - As a reflecting prism in some optical devices as periscope and binocular.	Dispersion of white light into seven colors.

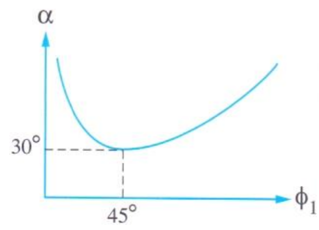
QUESTIONS ON
Chapter 2
LESSON FIVE

Minimum Deviation and Thin Prism

Interactive test

First Multiple choice questions

1 The opposite figure shows the relation between the first angle of incidence (ϕ_1) for a light ray which is falling on one of the faces of a triangular prism and the angle of deviation (α), so :



(i) The apex angle of the prism equals ....

a) 30° b) 45°

c) 60° d) 90°

(ii) The refractive index of the prism equals ....

a) 1.5 b) $\sqrt{2}$ c) 1.33 d) $\sqrt{3}$

2 If the refractive index of the material of an equilateral prism is $\sqrt{2}$, the angle of minimum deviation of the prism is ....

a) 30° b) 40° c) 45° d) 49°

3 If a light ray is incident on an equilateral prism and undergoes minimum deviation, so the second angle of incidence equals ....

a) 30° b) 45° c) 60° d) 90°

4 When the prism is being at minimum deviation, the refractive index of the prism is determined from the relation : ....

a) $n = \frac{\sin \phi_1}{\sin \theta_2}$ b) $n = \frac{\sin \frac{(\alpha_o + A)}{2}}{\sin \frac{A}{2}}$ c) $n = \frac{\sin \phi_1}{\sin \phi_2}$ d) $n = \frac{\sin A}{\sin \alpha}$

5 The ratio between the refractive index of the material of a triangular prism for violet light and the refractive index of the material of the same prism for red light is ....

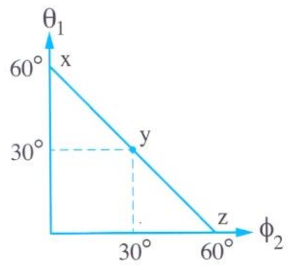
a) larger than one b) less than one c) equal to one d) indeterminable

6 At the increase of the wavelength of a falling light ray on one of the faces of a triangular prism at minimum deviation, the minimum deviation angle ....

a) increases b) decreases

c) doesn't change d) cannot be determined

7 The opposite graph shows the relation between the first angle of refraction (θ_1) of a light ray falling on a triangular prism and the second angle of incidence (ϕ_2). If the angle of minimum deviation is 30°, so :



(i) The relative refractive index of the prism equals ....

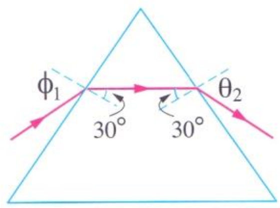
(a) $\sqrt{2}$ (b) 1.48 (c) $\sqrt{3}$ (d) 1.55

(ii) The angle of emergence of the light ray equals ....

(a) 15° (b) 30° (c) 45° (d) 60°

---

8 The opposite figure shows a triangular prism where a light ray falls on its face at an angle ϕ_1 and emerges from the other face at an angle θ_2, so the ratio $\frac{\sin \phi_1}{\sin \theta_2}$ equals ....

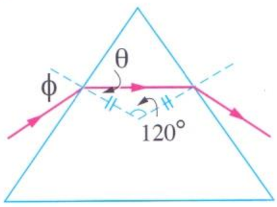


(a) $\frac{1}{2}$ (b) 1

(c) $\frac{1}{\sqrt{2}}$ (d) $\frac{1}{\sqrt{3}}$

---

9 If the opposite figure shows the deviation of a light ray through a prism of refractive index $\sqrt{3}$, so ....



	ϕ	α
(a)	30°	30°
(b)	30°	60°
(c)	60°	30°
(d)	60°	60°

---

10 A thin prism has an apex angle of 5° and its refractive index is 1.6, so the deviation angle of light through it equals ....

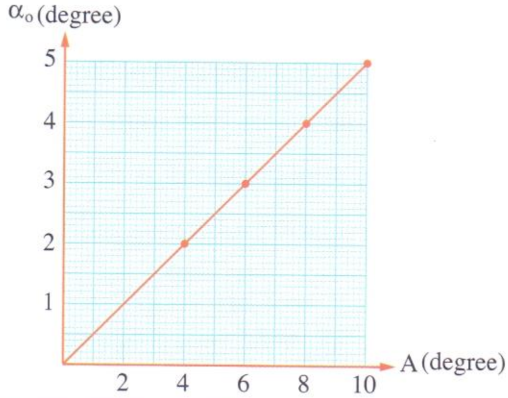
(a) 3° (b) 5° (c) 6° (d) 8°

---

11 If the angle of deviation of the light in a thin prism equals its apex angle, the refractive index of the prism equals ....

(a) 1 (b) 2 (c) $\frac{\sqrt{2}}{2}$ (d) $\sqrt{2}$

12 The opposite graph depicts the relation between the apex angles of different thin prisms that are made of the same material and the angle of deviation of light in each of them, so the refractive index of the prism's material equals ....



ⓐ 1.2 ⓑ 2
ⓒ $\sqrt{2}$ ⓓ 1.5

13 A thin prism has an apex angle of 6°. If its refractive index for blue light is 1.65 and for red light is 1.6, so the angular dispersion between blue light and red light equals ....

ⓐ 0.1° ⓑ 0.2° ⓒ 0.3° ⓓ 0.5°

14 If the summation of the refractive indices of blue and red light of a thin prism is 3.1 and the difference between them is 0.1, so the dispersion power of the prism is ....

ⓐ 1.1 ⓑ 0.2 ⓒ 0.18 ⓓ 0.14

15 Two thin prisms are made of different materials, if the refractive indices of red light and blue light in the first prism are 1.48 and 1.56 respectively and for the second one are 1.63, 1.69, so the ratio between the dispersion power of the first and that of the second is ....

ⓐ $\frac{11}{13}$ ⓑ $\frac{11}{15}$ ⓒ $\frac{22}{13}$ ⓓ $\frac{13}{22}$

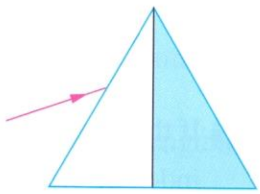
16 A thin prism has an apex angle of 10° and refractive index 1.6, if it is submerged in a liquid of refractive index 1.25, so the deviation angle of the prism is ....

ⓐ 2.5° ⓑ 2.8° ⓒ 3.5° ⓓ 6°

17 The ratio of the angle of minimum deviation of a prism in air to its value when it is dipped in water is .... $\left(\text{where : } n_g = \frac{3}{2}, n_w = \frac{4}{3}\right)$

ⓐ $\frac{1}{8}$ ⓑ $\frac{1}{2}$ ⓒ $\frac{3}{4}$ ⓓ $\frac{1}{4}$

18 A light ray is incident upon a prism in minimum deviation position and suffers a deviation of 34°. If the shaded half of the prism is removed, the ray will ....



ⓐ suffer a deviation of 34°
ⓑ suffer a deviation of 68°
ⓒ suffer a deviation of 17°
ⓓ not come out of the prism

(19) When a light of wavelength λ is incident on an equilateral prism that is kept in its minimum deviation position, it is found that the angle of deviation equals the apex angle of the prism. The refractive index of the material of the prism for the wavelength λ is ....

(a) $\sqrt{3}$ (b) $\frac{\sqrt{3}}{2}$ (c) 2 (d) $\sqrt{2}$

(20) A ray is incident at an angle of incidence ϕ_1 on one of the faces of a prism of small angle A and emerges normally from the opposite face. If the refractive index of the material of the prism is n, the angle of incidence ϕ_1 is nearly equal to ....

(a) $\frac{A}{n}$ (b) $\frac{A}{2n}$ (c) nA (d) $\frac{nA}{2}$

Second Essay questions

1 **What happens when** a beam of white light falls on a triangular prism which is set in the minimum deviation position ?

2 **Explain the following statements :**

(1) In the same triangular prism the angle of minimum deviation changes by the change of wavelength.

(2) The violet light deviates more than the red light when they pass through a prism.

(3) Triangular prisms disperse white light while transparent cuboids don't.

3 **What are the factors on which the following quantities depend ?**

(1) The minimum angle of deviation in a prism.

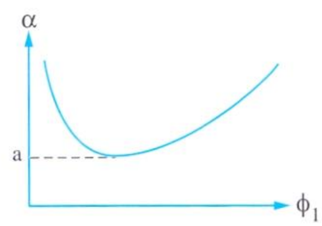
(2) The angle of deviation in the thin prism.

(3) The angular dispersion of a thin prism.

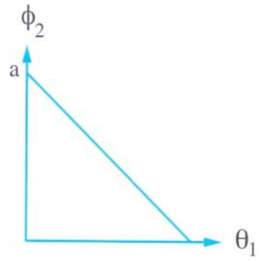
(4) The dispersion power (ω_α) of a thin prism.

4 **What is the quantity that point (a) represents in each of the following ?**

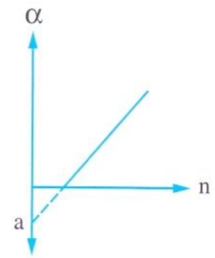
(a) The relation between the first angle of incidence (ϕ_1) for a light ray in a prism and the angle of deviation of the ray (α).



(b) The relation between the first angle of refraction (θ_1) and the second angle of incidence (ϕ_2) for a ray falling on a prism ?



(c) The relation between the refractive indices (n) of different thin prisms and the angle of deviation for each of them (α) :



Third Problems

1 A glass prism has ($\alpha = \phi_1 = A = 60°$), **calculate** the refractive index of the prism's material. ($\sqrt{3}$)

2 If the deviation angle for a light ray that falls on an equilateral triangular prism at a minimum deviation is 30°. **Find :**

(a) The refractive index of the prism material.

(b) The incidence angle on the prism.

(c) The emergence angle. ($\sqrt{2}$, 45° , 45°)

3 A triangular prism has an apex angle of 60° and a refractive index $\sqrt{2}$. **Calculate** the angle of deviation and the angle of incidence at the minimum deviation position. (30° , 45°)

4 A light ray fell on an equilateral triangular prism. If the angle of incidence = The angle of emergence = 40°, **calculate :**

(a) The angle of deviation of the light ray.

(b) The refractive index of the prism. (20° , 1.29)

5 The following table shows the relation between refraction angles of a light ray which is incident on one face of a triangular prism (θ_1) and the second incidence angles of the same ray on the other face of the prism (ϕ_2) :

θ_1 (degree)	0	15	20	a	35	40
ϕ_2 (degree)	b	45	40	30	25	20

(a) **Draw** the graphical relation between θ_1 on the (x-axis) and ϕ_2 on the (y-axis).

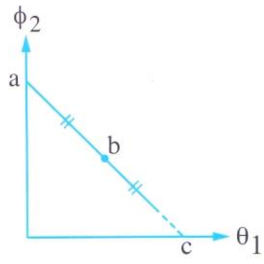
(b) **From the figure find :**

1- The values of a and b.

2- The refractive index of the prism material if you know that the deviation angle (α) at the position of minimum deviation = 37.2° (30° , 60° , 1.5)

---

6 The opposite graph represents the relation between the first angle of refraction (θ_1) and the second angle of incidence (ϕ_2) when a light ray passes through an equilateral triangular prism :



(a) **What** does the angle at point c represent ?

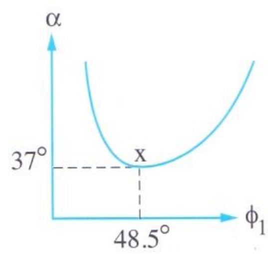
(b) **Which** point (a , b or c) represents the minimum angle of deviation position ? **Give reason.**

(c) **Find** the refractive index of the prism's material if the minimum angle of deviation = 30° (60° , b , $\sqrt{2}$)

---

7 The opposite graph represents the relation between the angles of incidence (ϕ_1) and the deviation angles (α) of a light ray falling on the face of a triangular prism.

Using the values shown in the figure calculate :



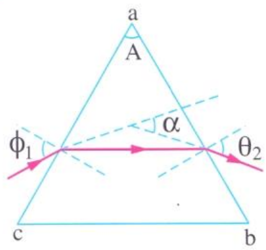
(a) The emergence angle of the ray.

(b) The apex angle of the prism.

(c) The refractive index of the prism material. (48.5° , 60° , 1.5)

---

8 The opposite figure shows an equilateral prism of refractive index 1.6, **calculate** the angle of incidence of the light ray which falls on face ac when $\phi_1 = \theta_2$ (53.13°)



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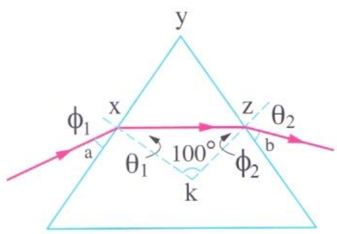
9 The opposite figure shows a light ray falling on a triangular prism at an angle ϕ_1, if $\hat{a} = \hat{b}$ and $\phi_1 = 1.5\ \theta_1$,

calculate :

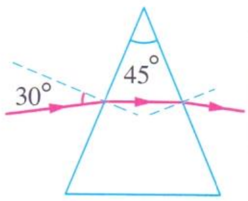


(a) The apex angle of the prism.

(b) The first angle of incidence (ϕ_1).

(c) The refractive index of the prism. (80° , 60° , 1.35)

10 An isosceles triangular prism, whose apex angle equals 45°, is made of a transparent material. If a light ray falls on one of its faces at an angle of 30° and refracts inside the prism parallel to the base, **calculate :**



(a) The angle of emergence of the light ray from the prism.

(b) The angle of deviation of the ray.

(c) The refractive index of the prism. (30° , 15° , 1.31)

11 The apex angle of a triangular prism is 60°, its refractive index is 1.5. If it's submerged in a liquid whose refractive index is 1.3. **Calculate :**

(a) The minimum angle of deviation.

(b) The first angle of incidence at the position of minimum deviation. (10.2° , 35.1°)

12 A thin prism of an apex angle 4° and refractive index 1.5. **Find** the angle of deviation of a light that passes through it. (2°)

13 A white light falls on the face of a thin glass prism whose angle is 8°, the refractive index of its material for blue and red colors are 1.7 and 1.5 respectively, **calculate :**

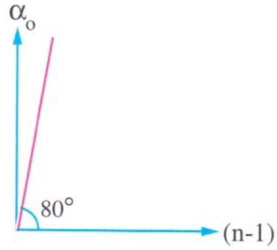
(a) The angular dispersion in the prism.

(b) The dispersive power of the prism.

(c) The deviation angle of the red and blue colors. (1.6° , 0.33 , 4° , 5.6°)

14 A thin prism has an apex angle 8°, a refractive index 1.4 for red light and 1.6 for blue light. **Calculate** the average deviation angle. (4°)

15 The opposite figure shows the relation between the angle of minimum deviation for different material prisms which have the same apex angle and (n – 1) for these prisms drawn with the same scale.



Find the apex angle of these thin prisms. (5.67°)

16 In a practical experiment to study the relation between the apex angle for a number of thin prisms made of glass and the deviation angle (α_o) of a light ray, the following results were obtained :

A (degree)	2	3	4	5	6	7
α_o (degree)	1	1.5	a	2.5	3	3.5

(a) **Draw** the graphical relation between the apex angle of each prism (A) on (x-axis) and the deviation angle (α_o) on (y-axis).

(b) **From the graph find :**

1- The value of a.

2- The refractive index of glass. (2° , 1.5)

17 In one of the experiments to find the relation between the deviation angle (α_o) and the refractive index (n) of the prism material, the following results were obtained :

n	1.2	1.4	a	1.8	2	2.2
α_o (degree)	1.4	2.8	4.2	5.6	b	8.4

(a) **Draw** the graphical relation between (n) on (x-axis) and (α_o) on (y-axis).

(b) **From the graph find :**

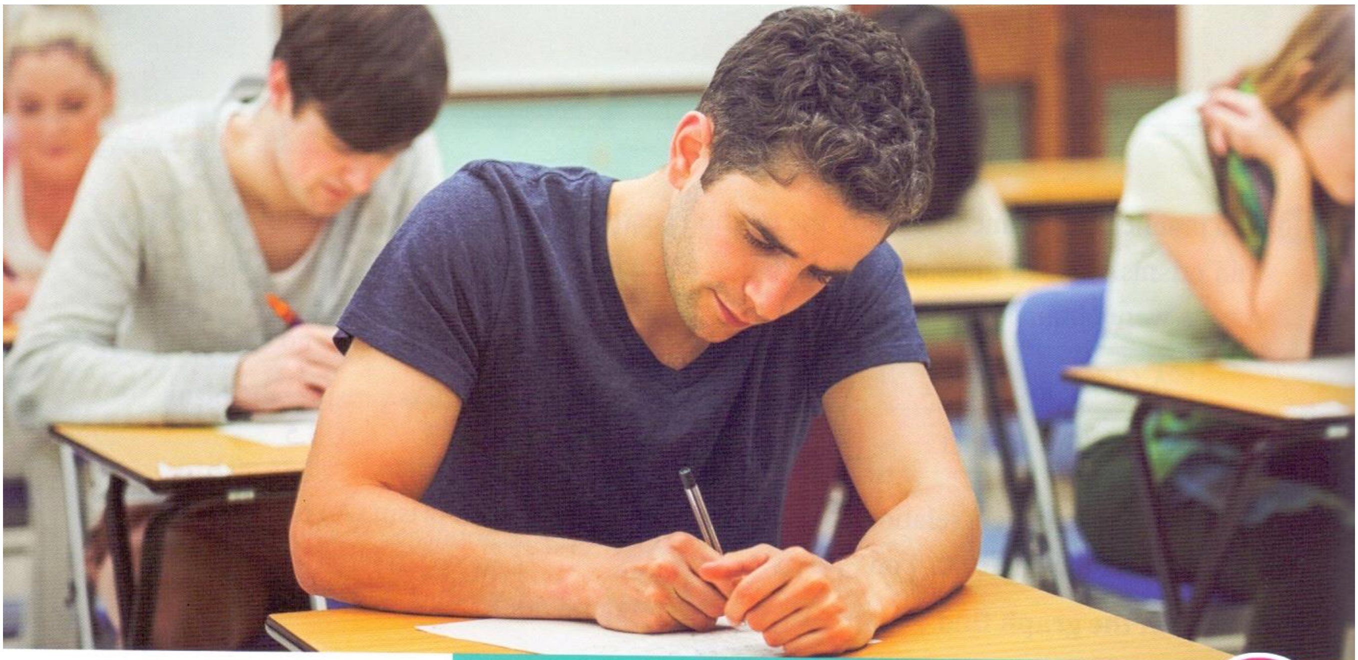
1- The values of a and b.

2- The apex angle of the prism by two different methods. (1.6 , 7° , 7°)

18 Two thin prisms are placed inversely such that one of them cancels the deviation which is formed by the other. The apex of the first prism equals 8° and its refractive index is 1.5. If the apex of the second prism is 6°, **calculate** its refractive index. (1.67)

19 Two thin prisms have the same angular dispersion, one of them is made of crown glass, has an apex angle of 6.25°, an average refractive index 1.5 and a dispersion power 0.048. If the other is made of rock glass where it has an apex angle of 10° and dispersion power 0.024, **calculate** its average refractive index. (1.625)

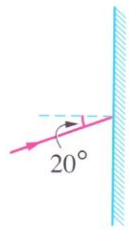
20 A thin prism of refractive index 1.5 is submerged in water of refractive index 1.33. If the light rays which fall on the prism deviated at an angle of deviation 1.04°, **calculate** the apex angle of the prism. (8°)



TEST ON Chapter 2 Light

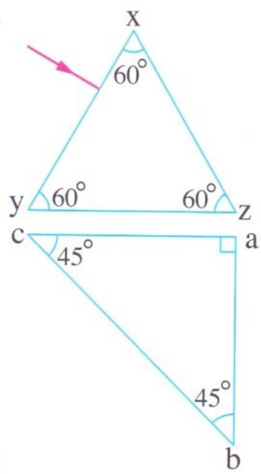
First Choose the correct answer

1. The opposite figure shows a light ray falling on a plane mirror at an angle of incidence 20°. If the mirror is rotated in clockwise direction by an angle of 20°, the angle of reflection from the mirror ....



(a) increases 20° (b) decreases 20°
(c) increases 40° (d) decreases 40°

2. The opposite figure shows two different prisms which are made of the same material of refractive index 1.5. If a light ray falls perpendicularly on face xy, it will emerge perpendicularly from face ....

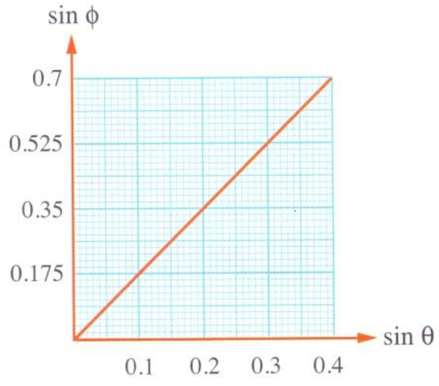


(a) xz
(b) ac
(c) bc
(d) ab

3. If Young's double-slit experiment is conducted twice with different light sources, the ratio between their wavelengths is $(\frac{\lambda_1}{\lambda_2} = \frac{7}{8})$, the ratio between the widths of the observed fringes for each light will be $\frac{(\Delta y)_1}{(\Delta y)_2}$ = ...

(a) $\frac{8}{7}$ (b) $\frac{7}{8}$ (c) $\frac{64}{49}$ (d) $\frac{49}{64}$

4 The opposite graph depicts the relation between sine of the angle of incidence of a light ray in a transparent medium and sine of the angle of refraction of the ray in another medium when the ray travels between them. If the wavelength of the light ray in the first medium was 700 nm, the wavelength of the ray in the second medium equals ....



(a) 550 nm (b) 500 nm

(c) 450 nm (d) 400 nm

---

5 Blue light ray of wavelength 420 nm in air fell on the surface of water. If the refractive index of water is $\frac{4}{3}$, the wavelength of the blue light in water equals ....

(a) 300 nm (b) 315 nm (c) 480 nm (d) 560 nm

---

6 In Young's double-slit experiment, if the distance between the fourth dark fringe and the central fringe is x, then the distance between the central fringe and the first bright fringe equals ....

(a) $\frac{x}{4.5}$ (b) $\frac{x}{4}$ (c) $\frac{x}{3.5}$ (d) $\frac{x}{3}$

---

7 A light ray falls at an angle of incidence 0° on one of the faces of a triangular prism whose apex angle is 45°. If the ray emerges tangentially from the opposite face, the speed of light in the prism equals .... ($c = 3 \times 10^8$ m/s)

(a) 1.96×10^8 m/s (b) 2.08×10^8 m/s

(c) 2.12×10^8 m/s (d) 2.41×10^8 m/s

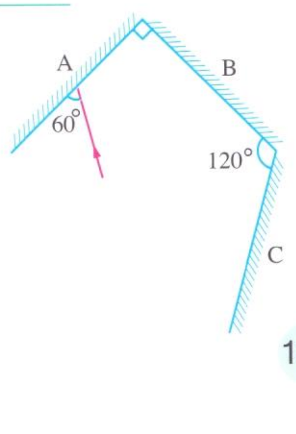
---

8 A thin prism has an apex angle which equals double the angle of deviation of a light ray that passes through the prism, so the refractive index of the prism equals ....

(a) $\sqrt{2}$ (b) 1.5 (c) $\frac{\sqrt{2}}{2}$ (d) 1.75

---

9 In the opposite figure, if a light ray falls on mirror A, its angles of incidence on both mirrors B and C respectively are ....



(a) 30° , 60° (b) 60° , 30°

(c) 60° , 60° (d) 45° , 60°

10. A light ray fell on one of the faces of an equilateral triangular prism, the ray refracted parallel to the base and emerged with an angle 60° , so the first angle of incidence equals ....

(a) 30° (b) 45° (c) 60° (d) 90°

Second Answer the following questions

11. **Can** a transparent medium have a refractive index less than one ? **Explain your answer.**

....

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12. **In which** phenomena; refraction or diffraction, does the wavelength of light remain unchanged ? **And why ?**

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13. When putting a blue light source in the center of a glass cube which is surrounded by white screens around the lateral faces of the cube, a circular light spot appeared on each of the screens, **explain what happened.**

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14. Two thin prisms deviate light rays by the same deviation angles and they have refractive indices 1.5 and 1.75. If the apex angle of the first prism is 9°, **calculate** the apex angle of the second prism.

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15 A student carries out Young's double-slit experiment by using a monochromatic red light, so an interference pattern appears on the screen. **How** can the student get the same interference pattern by using a monochromatic blue light ?

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16 If you have two different transparent materials A and B and you want to make a double layer optical fiber. **Which** of the two materials will be used for the core and **which of them** for the external layer ? **Explain your answer.**

(knowing that : the refractive index of B is greater than that of A)

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17 A light ray fell on a triangular prism and emerged with an angle of deviation, **what would happen** to the angle of deviation if the prism was rotated slowly in such away that the incident ray gets closer to the base of the prism ?

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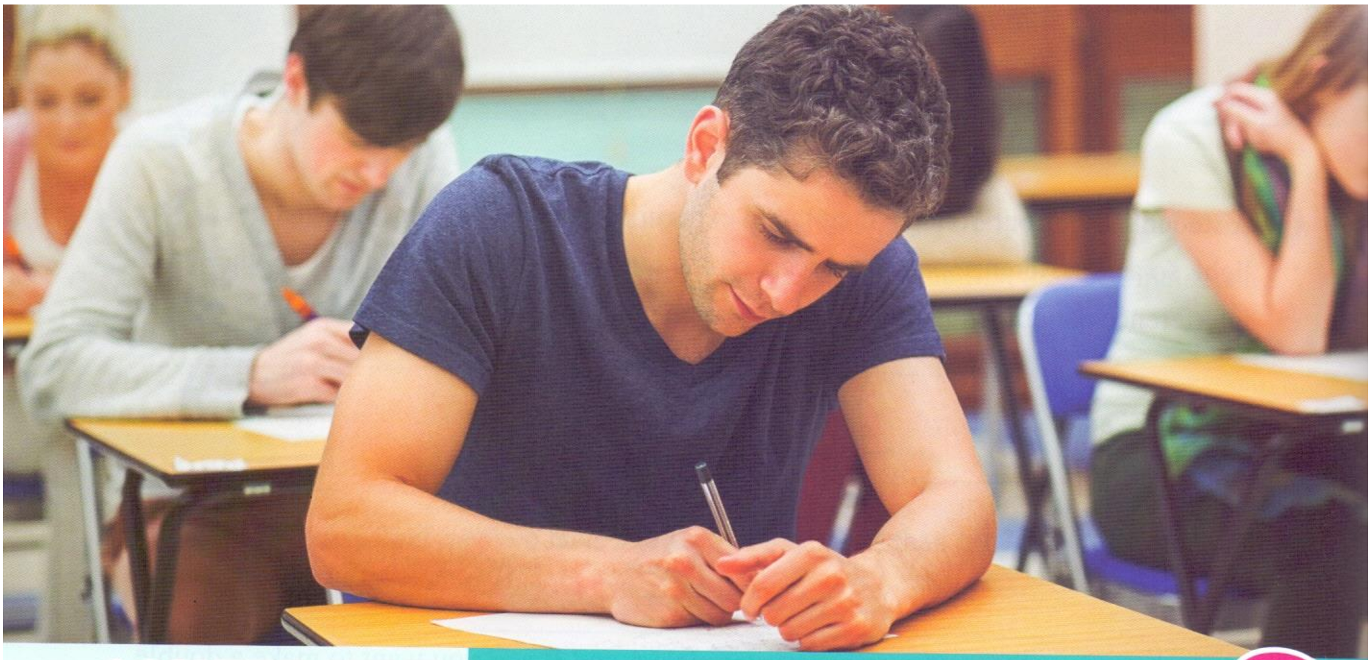


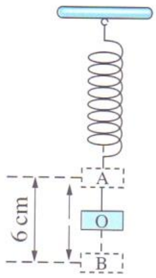
ACCUMULATIVE TEST ON Chapters 1 & 2

First Choose the correct answer

1. If the ratio between the frequency of the voice of a man to that of a girl is $\frac{7}{9}$, the ratio between the speeds of their voices respectively in air equals ....

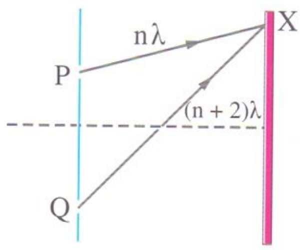
   (a) $\frac{7}{9}$ (b) $\frac{9}{7}$ (c) $\frac{9}{9}$ (d) $\frac{7}{1}$

2. The opposite figure shows a load vibrating with an average speed of 4 cm/s, so the frequency of the vibration equals ....



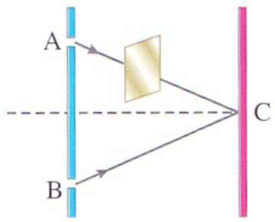
   (a) 6 Hz (b) 3 Hz
   (c) $\frac{1}{3}$ Hz (d) $\frac{2}{3}$ Hz

3. The figure shows a double-slit experiment where P and Q are the slits. If the path lengths PX and QX are $n\lambda$ and $(n + 2)\lambda$ respectively, where n is a whole number, λ is the wavelength and the central fringe is zero, what is formed at X ? ....



   (a) First bright fringe
   (b) First dark fringe
   (c) Second bright fringe
   (d) Second dark fringe

4 In Young's experiment, monochromatic light is used to illuminate the two slits A and B. Interference fringes are observed on a screen placed in front of the slits. Now if a thin glass plate is placed normally in the path of the beam coming from the slit A ....



ⓐ the fringes will disappear
ⓑ the fringe width will increase
ⓒ the fringe width will decrease
ⓓ there will be no change in the fringe width but the pattern shifts

5 If the critical angle for total internal reflection from a medium to vacuum is 30°, the velocity of light in the medium is .... ($c = 3 \times 10^8$ m/s)

ⓐ 3×10^8 m/s ⓑ 1.5×10^8 m/s ⓒ 6×10^8 m/s ⓓ $\sqrt{3} \times 10^8$ m/s

6 In two separate setups of the Young's double slit experiment, fringes of equal widths are observed when lights of wavelengths in the ratio 1 : 2 are used. If the ratio of the slit separation in the two cases is 2 : 1 respectively, the ratio of the distances between the plane of the slits and the screen in the two setups is ....

ⓐ 4 : 1 ⓑ 1 : 1 ⓒ 1 : 4 ⓓ 2 : 1

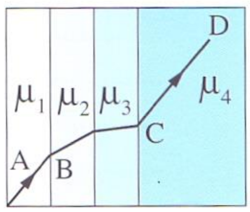
7 The frequency of a tuning fork is 384 per second and velocity of sound in air is 352 m/s. How far the sound has traversed while fork completes 36 vibration ....

ⓐ 3 m ⓑ 13 m ⓒ 23 m ⓓ 33 m

8 A light ray falls on one of the faces of a thin prism of an apex angle 9°, refractive index for the blue color 1.664 and refractive index for the red color 1.644, then the dispersive power for this prism equals ....

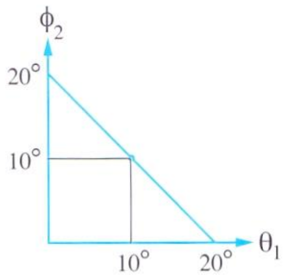
ⓐ 0.05 ⓑ 0.04 ⓒ 0.03 ⓓ 0.02

9 A ray of light passes through four transparent media with refractive indices μ_1, μ_2, μ_3 and μ_4 as shown in the figure. The surfaces of all media are parallel. If the emergent ray CD is parallel to the incident ray AB, we must have ....



ⓐ $\mu_1 = \mu_2$ ⓑ $\mu_2 = \mu_3$ ⓒ $\mu_3 = \mu_4$ ⓓ $\mu_4 = \mu_1$

10 The opposite graph represents the relation between the first refraction angle (θ_1) and the second angle of incidence (ϕ_2) when the light ray passes through a triangular prism, If the critical angle of the prism is 41.8°, then the minimum deviation angle of the falling light ray is ....



ⓐ 8.43° ⓑ 10.2°
ⓒ 15.46° ⓓ 20.25°

Second Answer the following questions

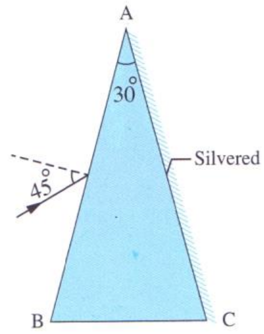
11. A tower clock makes a signal of light with a whistle every 1 hour. A man at 8 km from the tower sets his watch by the light signal of the tower. Another man sets his watch by the sound of the whistle. If the two watches of both men have a time difference 3 seconds, **calculate** the distance between the man who sets his watch by the whistle and the tower **and find which** of their watches is more accurate ?
(knowing that : speed of sound = 360 m/s, speed of light = 3×10^8 m/s)

12. If the distance between the second crest and the seventh one of a transverse wave is 20 m and the time interval between the first crest and the fifth one when they pass a certain point in the path of the wave motion is 0.1 s, **calculate :**
(a) The wavelength of the wave motion.
(b) The frequency of the source of disturbance.
(c) The wave velocity.

13. A light ray falls on water surface with an angle that equals 45° , **calculate** the confined angle between the reflected ray and the refracted ray.
(knowing that : the refractive index of water = 1.33)

14. Light ray of wavelength 5×10^{-7} m falls from air on the plane surface of a glass piece whose refractive index equals 1.5. **Calculate :**
(a) The speed of light in the glass.
(b) The frequency of light ray in the glass.
(knowing that : the speed of light in air = 3×10^8 m/s)

15 A prism ABC of angle 30° has its face AC silvered.
A ray of light is incident at an angle of 45° at the face AB and reflects back on itself at face AC. **Calculate** the refractive index of the material of the prism.



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16 A thin glass prism of refractive index 1.5 is put in a transparent liquid whose refractive index is 1.2, **calculate** the apex angle of the prism if the ray deviates by an angle 4 degrees.

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17 In one of the experiments to find the wavelength using Young's double slits experiment, if the distance between the double slits and the observation screen is 2 m, then the following results for the distance between two successive fringes of the same type (Δy) and the reciprocal of the distance between the two slits ($\frac{1}{d}$) were recorded :

$\Delta y \times 10^{-3}$(m)	10	b	18	25	30
$\frac{1}{d} \times 10^{4}$ (m^{-1})	0.9	1	a	2.1	2.5

(a) **Draw** the relation between (Δy) on the (y-axis) and ($\frac{1}{d}$) on (x-axis).

(b) **From the graph find :**

1- The value of both (a) and (b).

2- The wavelength of the used monochromatic light.

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